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A journal of plant ecology for eastern Australia

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Cunninghamia

A journal of plant ecology for eastern Australia

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Allan Cunningham, botanist and explorer (1791–1839)

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Cover: Lowland cushion plants (left) *Frankenia muscosa*, (centre) *Pultenaea purpurea*, (right) *Borya constricta*. (for details see Parsons & Gibson, this issue pages 177-184)

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SHORT COMMUNICATION

Phormium tenax (New Zealand Flax) — Norfolk Island native?

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Abstract: *Phormium tenax* (New Zealand flax) was one of the first plants found on Norfolk Island by Cook's expedition in 1774, and its potential value to the British navy was considered so significant that it appears to be one of the main reasons Norfolk Island (lat 29° 02'S; long 167° 57'E), about 780 km north of New Zealand, was colonised in March 1788. *Phormium tenax* has always been considered native to Norfolk Island, despite the realisation that Polynesian settlers had been there before the British. The absence of any records of it on nearby Phillip Island until 1967 however, contrasts with its reported abundance on Norfolk Island in the 1700s. If *Phormium* had been present on Norfolk earlier than about 15,000 years ago it would be expected to have colonised Phillip Island, particularly in habitats similar to those it occupied on Norfolk, because the two islands (now 6 km apart) were then part of a single, much larger island. The absence of *Phormium* pollen from fossilised pollen recently collected on Norfolk Island suggested to researchers that flax had been introduced to Norfolk Island by Polynesian settlers and should therefore not be regarded as native or indigenous. The lack of any recorded distribution of *Phormium* on Phillip Island before 1967 and its distribution there in 1978 provide evidence reinforcing this conclusion.

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Introduction

In October 1774, after mapping, naming and taking possession of the New Hebrides (now Vanuatu) and New Caledonia, one island of which he named the Isle of Pines (after the distinctive *Araucaria columnaris*), Lieutenant James Cook in the *Resolution* discovered and named Norfolk Island (lat 29° 02'S; long 167° 57'E)(Figure 1).The boats were hoisted out and the ship's officers and supernumeries set out to explore the island.

William Wales, the ship's astronomer, noted that (Wales 1774) '*Near the shore the ground is covered so thick with the New Zealand flax Plant that it is scarce possible to get through it.* [This] *Plant was now in its greatest perfection, the flowers ... just opening, and as might naturally be expected from the climate vastly more exuberant than at New Zealand;* [but a] *little way inland the woods are perfectly clear and easy to walk in*.' Many plants already known from New Zealand were recognised but the explorers did not notice any evidence of human occupation of Norfolk Island. Wales wrote: '*We saw no Inhabitants nor the least reason to believe it had ever been trod by Human feet before*.' Thus they believed everything they saw was natural, entirely free of human influence.

The expedition's botanists, father and son team Johann Reinhold Forster and Georg Forster, and Anders Sparrman, collected specimens of the flax plant on Norfolk Island, but in 1775 when the Forsters formally named it *Phormium tenax*, they used a New Zealand collection as the type specimen.

Cook was impressed by the potential of Norfolk Island (area 3450 hectares) to provide timber and fibre for the Royal Navy. The timber of the '*pines*' was '*exactly of the same nature as the Quebeck pines*' and the trees were huge and straight. They seemed ideal for masts and spars. Cook knew how highly the Maoris in New Zealand valued the flax as a fibre plant and thought it would be invaluable for making ropes and sails. Accordingly, of all the islands discovered on the voyage, tiny Norfolk stood out for its potential value to Britain, largely because of its flax.

Because of Cook's enthusiasm for the potential value of the flax, the British Government's 1787 instructions to Arthur Phillip, commodore of the First Fleet and first Governor of New South Wales, described the flax '*not only as a means of acquiring Clothing for the Convicts and other persons who may become settlers, but from its superior excellence for a variety of maritime purposes and as it may ultimately may become an Article of Export*.' Phillip was instructed: '*you are, as soon as circumstances will admit of it, to send a small Establishment* [to Norfolk Island] *to secure the same to us, and prevent its being occupied by the subjects of any other European Power*' (draft dated 20 April 1787 *Historical Records of New South Wales*, Vol. 2, Part 2).

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Distribution of Phormium *on Norfolk and Phillip Islands*

Consequently, in February 1788 less than three weeks after the First Fleet arrived at Sydney Cove, Lieutenant Philip Gidley King set out to develop a British colony on Norfolk Island. Phillip's instructions to King were to '*immediately to proceed to the cultivation of the Flax Plant, which you will find growing spontaneously on the island*' (Phillip 1788). King was not told how to identify the flax. Although he searched for it he did not recognise it for more than two weeks. As he wrote, it '*in no manner resembles ye Flax of Europe its appearance being more like Flags*'.

At the time of European settlement of Norfolk Island in 1788 the only naturally treeless areas were the flax-covered sea cliffs (Macphail et al. 2001). All available information suggests flax was essentially coastal.George Raper, a midshipman of HMS *Sirius*, stranded on Norfolk Island when the ship was wrecked in March 1790, wrote of the flax '*As for the flax, I can only say, there is an abundance of it in all parts of the Sea Coast of this Island, (but not inland)*'.

In September 1792 the amateur naturalist William Patterson wrote to Sir Joseph Banks: '*Near the shore on the steepest places where there is any soil it is covered with the Flax plant and interspersed with very lofty pines, some of them growing even on naked rocks where there is not the smallest appearance of earth. The Pine and Flax plant seem to thrive best where they are exposed to the sea air, the latter indeed is never found inland.*' (quoted by Holloway, 1977).

Maiden (1904) said of the flax that '*Its natural habitat on the Island is the sides of steep banks or cliffs.*' R.B. Laing (1914) described the flax on Norfolk Island as '*undoubtedly native, growing on dry bare hillsides and in such situations as P. Cookianum is usually found in on the New Zealand hills.*' Laing did not see flax in any swampy places or beside watercourses.

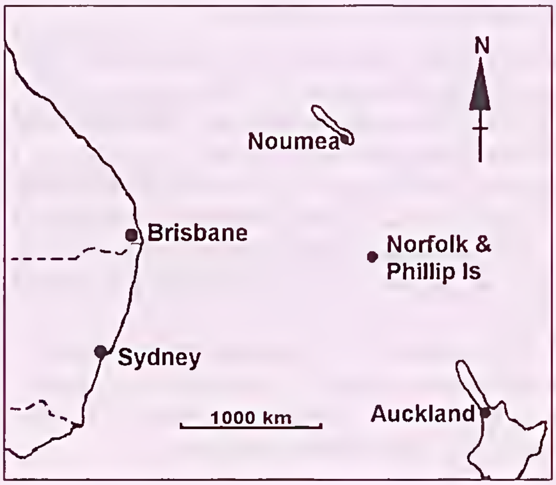

Fig. 1 Location of Norfolk Island in the South Pacific Ocean.

In December 1788 King made his first (and apparently *the* first) visit to Phillip Island (about 200 ha in area) 6 km south of Norfolk Island. He described the vegetation briefly but did not mention seeing any flax. As he was so familiar with flax and its importance this suggests he did not see it on Phillip Island.

Despite later visits to Phillip Island by Ferdinand Bauer (who was responsible for original drawings of Norfolk Island plant species) in 1804–05, Allan Cunningham in 1830, J.H. Maiden and J.L. Boorman in 1902 and R.B. Laing in 1912, flax was not reported there until 1967, when it was growing in a small area far from the coast at an altitude of about 140 m. Phillip Island was almost devoid of vegetation by then due to the effects of pigs, released there in 1793, and goats and rabbits released by 1830. The distribution of *Phormium* on Phillip Island prior to rabbit eradication in 1986 contrasts completely with its reported distribution on Norfolk Island in the early years of British occupation.

Opportunities for Phormium *to colonise during the ice ages*

Norfolk and Phillip Islands were formed by volcanic activity 2.3 to 3 million years ago (Jones & McDougall 1973). Both islands sit almost centrally on the Norfolk Plateau, the eroded top of a volcanic seamount 100 km by 35 km. Although 6 km apart, they would be connected by dry land at sea levels more than about 40 m below the present level (BPL). A sea level 50 m BPL would expose an island about 35 km long with Norfolk and Phillip forming mountains near its centre, and the entire Norfolk Plateau with ten volcanic hills or mountains (including Norfolk and Phillip), would be exposed when sea level was 75 m BPL.

Lambeck and Chappell (2001) present sea level data for the duration of the last ice age which show that sea level was at least 50 m BPL between about 71,000 and 10,000 years ago, and was at least 75 m BPL from about 37,000 to 13,000 years ago. Thus Norfolk and Phillip were part of a single island for at least 60,000 of the last 75,000 years, and for about 24,000 years that island was 100 km long and 35 km wide. Rabineau et al. (2006) provide sea level data for the last 600,000 years which show that sea level was at least 50 m BPL for more than half the time, whereas the present sea level occurred only briefly and rarely. At least 17 glacial cycles, each approximately 100,000-years-long, of sea level fall and rise have occurred during the last 1.8 million years (Cronan 2000).

An extinct *Phormium* (judged by fossil pollen) grew in New Zealand during the early Tertiary, prior to the evolution of the modern species, one of which, *Phormium tenax*, must have colonised Norfolk, the Chatham and Auckland Islands at quite a late Cenozoic date (post-glacially in the Auckland Islands) (Fleming 1976). Thus *Phormium* was apparently present on New Zealand and available, if the opportunity arose, to colonise Norfolk Island from the time Norfolk and Phillip Islands were formed by volcanic eruptions more than two million years ago.

If *Phormium* had been present on Norfolk Island during the last ice age it almost certainly would have migrated across the lowlands during the 60,000 years they were exposed and would have colonised Phillip Island, particularly around the (now) coastal cliffs. As its recorded distribution on Phillip Island contrasts with what would be expected from its distribution on Norfolk Island, *Phormium* would appear to have been absent from Norfolk Island up to perhaps 15,000 years ago.

Polynesian settlers on Norfolk

Less than a month after arriving at Norfolk Island in 1788, King was dismayed to find that some of the first agricultural seedlings to germinate were destroyed by rats. This was the first evidence, though not immediately recognised, that people had been on the island before Cook's discovery in 1774. The rats turned out to be *Rattus exulans*, the Polynesian or Pacific rat. A dugout canoe similar to those made by the Maoris in New Zealand was found on a beach well above high tide level, but it might have drifted there. By August 1788 wild bananas had been found growing by a creek near the settlement, providing further evidence of a previous settlement on the island. Stone tools of Polynesian style were later found. In November 1792 King wrote of a convict party which had gone out to Phillip Island and found a number of scorpions, lizards and centipedes. King (quoted in Cogger et al. 1983) observed '*It is remarkable that no reptile of that or any other kind have ever been found or heard of on* [Norfolk] *island*.' Phillip Island did not have rats. The rats had evidently been on Norfolk Island long enough to exterminate the scorpions, lizards and centipedes.

Progressively King recognised the ancient settlement of Norfolk Island by Polynesians, possibly from New Zealand (Anderson & White 2001). The Polynesians were seen to be the source of the rats and bananas. Polynesian voyagers were known to take with them plants and animals which were useful, but until about twenty years ago little consideration seems to have been given to what else the Polynesians might have brought to Norfolk.

In 1995 the Norfolk Island Prehistory Project found a Polynesian settlement site behind Emily Bay (Anderson et al. 2001). Field work continued until 1999 and Polynesian plant introductions were investigated by analysis of fossilised pollen grains and spores recovered from different depths in the soil profile. *Phormium* pollen was identifiable to species level. The investigation showed that some plant species which had been considered possible introductions were present on the island long before the earliest known Polynesian settlement, but failed to find fossilised *Phormium* pollen in a soil unit (at 147 – 167 cm depth) dated at about 1000 years before present and considered to represent soil conditions particularly suitable for establishment of *Phormium*. This led to the conclusion that Polynesians introduced *Phormium* to Norfolk Island some time between about 1200 and 1774 (Macphail et al. 2001).

Discussion

Phormium tenax (New Zealand flax) is an invasive plant in many parts of the world, and is proving a threat to sensitive floras (Trustees of the Royal Botanic Gardens, Kew 2009). The Global Compendium of Weeds (Randall 2007) lists flax as a weed in (*inter alia*) Pacific Islands, Hawaii, New South Wales and Victoria.

The natural introduction of *Phormium tenax* to Norfolk Island is hypothetically possible. Seeds might have been carried in mud on a bird's feet. This apparently did not happen in the first two million years, even during the many long periods of lower sea level when the island was much larger, and more suitable habitats were almost certainly available in the extensive lowlands below the present sea level. The apparent failure of *Phormium* to arrive naturally in the previous two million years suggests its natural arrival in the last 800 (or even 15,000) years is highly improbable.

Like Europeans, Polynesians have been responsible for the spread of exotic plants into the southwest Pacific. Obvious examples are food species such as bananas (*Musa paradisiaca*), coconuts (*Cocos nucifera*) and sweet potato (*Ipomoea batatas*). Less clear-cut examples are the New Zealand flax (*Phormium tenax*), Ti (*Cordyline*) and the sow thistle (*Sonchus oleraceus*) (Macphail *et al.* 2001).

The available evidence suggests quite strongly that Norfolk Island was colonised from Raoul Island by Polynesian people who had come from New Zealand or, if they came directly from somewhere else in East Polynesia, had lived on Raoul Island amongst people who had originated in or visited New Zealand (Macphail et al. 2001). New Zealand flax was the principal fibre plant of the Maori in New Zealand (Given & Harris 1994), and as their most useful fibre plant, Polynesian settlers could have brought it to Norfolk Island about 800 years ago. The complete absence of *Phormium* pollen at a site known to have been near a ridge described as being covered by this plant in 1774 is difficult to explain unless it was introduced onto Norfolk Island by Polynesians between about 1200 and 1774 (Macphail et al. 2001; Anderson and White 2001.

Phormium tenax has always been considered to be native (i.e. occurring naturally, unassisted by people) to Norfolk Island and therefore to Phillip Island (e.g. *Flora of Australia* – Green 1994). More recently it has been described as indigenous to New Zealand, Norfolk Island, and the Chatham Islands (Wehi & Clarkson 2007) and native to Phillip Island, specifically (Mills 2009).

Combining all the available evidence provides strong justification for considering that *Phormium* was brought to Norfolk Island by Polynesians, probably between 800 and 600 years ago, and so is not a native species. Similarly the Pacific rat (*Rattus exulans*) has long been recognised as having been brought to the island by Polynesians and thus is not generally considered native. Both Pacific rats and black rats (*Rattus rattus*) have been controlled in Norfolk Island National Park by intensive baiting on the basis that they are not native and their impact on indigenous plants and animals is undesirable.

In 1986 the rabbits on Phillip Island were eradicated and plant regeneration has been spectacular. The issue of whether *Phormium tenax* is native has practical significance because the island is part of Norfolk Island National Park. Its manager, Parks Australia, is influencing the revegetation of the island, planting native species and controlling weeds in attempting to restore the natural vegetation. *Phormium* has been treated as native and actively propagated and distributed. As *Phormium* is a vigorous weed in some other places where it has been introduced, if it is not originally native to Phillip Island, spreading it could be ecologically detrimental, working against the restoration of the island's ecosystem.

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SHORT COMMUNICATION

Was *Phormium tenax* introduced to Norfolk Island by the Polynesians?

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Abstract: Phormium tenax (New Zealand Flax) is a large rhizomatous perennial herb with a natural distribution restricted to the southwest Pacific, primarily on the New Zealand islands. The species' extra-New Zealand distribution is confined to smaller islands to the north and east, namely the Chatham Islands, Raoul Island in the Kermadecs, Campbell Island, the Auckland Islands and Norfolk Island. The species may have been introduced to some of these islands.

The species has always been treated as indigenous to Norfolk Island (lat 29° 02'S; long 167° 57'E, 780 km north of New Zealand). Recently, it has been suggested the Polynesians may have introduced *Phormium tenax* to that island in the distant past. A review of the evidence for its indigenous and introduced status on Norfolk Island is presented, concluding that the evidence either way is inconclusive, but that the indigenous status of the species is completely feasible. Taxonomic and/or genetic studies, with comparisons to the taxa in New Zealand and elsewhere, would provide useful information on the status of the plants on Norfolk Island.

***Cunninghamia* (2009) 11(2): 171–175**

Introduction

The large, clump-forming herbaceous plant *Phormium tenax* J.R. Forst & G. Forst. (variously placed in the Agavaceae, Phormiaceae or Hemerocallidaceae), generally known as New Zealand Flax because of its prevalence in that country, has always been treated as indigenous to Norfolk Island (e.g. Laing 1914, Fleming 1976, Green 1994). In addition to Norfolk Island the species is considered indigenous to the North and South Islands of New Zealand, Stewart and other offshore islands, and the Chatham Islands. It is usually considered to have been introduced to Raoul Island in the Kermadecs, Campbell Island and the Auckland Islands, either by Maori or early European whalers or sealers. The species is introduced to and is a significant pest species in some places, including Hawaii. Its numerous cultivars are widely known in the nursery industry around the world. Wehi and Clarkson (2007) provide a comprehensive review of all aspects of *Phormium tenax*.

Phormium tenax was named by the botanical duo, Johann Reinhold Forster and his son Georg, who accompanied James Cook on the *Resolution* on Cook's second Pacific expedition in 1772–1775. The origin of their type specimen is Queen Charlotte Sound in New Zealand, gathered there during that expedition. The Maori had long known of the plant and used it for a wide variety of purposes, ranging from weaving, to cosmetics and raft making; the Maori name for Flax is *harakeke*.

Cook's report of abundant pines *Araucaria heterophylla* and Flax on Norfolk Island, both potentially very useful materials for the Royal Navy, prompted the European settlement of the island in 1788. The pines proved to be largely unsuitable for masts and spars, uses envisaged by Cook, because of the way the lateral branches are attached to the trunk, causing weakness in the timber. Although approached with high expectations, the exploitation of Flax on Norfolk Island was generally unsuccessful, despite several years of attempting to tease a useful product from its fibres.

Phormium tenax was common and grew densely around the cliffs of Norfolk Island in 1774, when James Cook made the European discovery of the island. In March 1788 during his early explorations of the island , Philip Gidley King, the first commandant on Norfolk Island, wrote, while climbing down the cliffs to Anson Bay, "*we found our road must be down ye hill which is perpendicular & quite full of a large kind of Iris* [Flax] …" (Fidlon & Ryan 1980). King later noted in his report on the conditions on Norfolk Island dated 18 October 1796 that "*flax needs no cultivation, as it grows sufficiently abundant on all the cliffs on the island …*".

Philip Gidley King instructed convicts to harvest the plant from natural occurrences and to prepare it to make cloth.

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Their early attempts largely failed. King continued to believe in the possibility of a Flax industry on the island, but by 1791 was beginning to become despondent over efforts to successfully extract useable fibres. In his report of that year, King wrote that "*every effort has been tryed to work it, but I much fear that until a native of New Zealand can be carried to Norfolk Island that the method of dressing that valuable commodity will not be known, and could that be obtained, I have no doubt but Norfolk Island would very soon cloath the inhabitants of New South Wales*" (Historical Records of NSW, Vol. I Pt. 2, p. 429).

Two Maori men from the North Island of New Zealand were taken to Norfolk Island in 1793, but were of little help in the preparation of the Flax, as it was apparently women's work. In the end, King's optimistic report to Governor Phillip back in Sydney, subsequently passed on to Lord Sydney in London, was never realised: "*the flax-plant will supply the settlers on that island* [Norfolk] *with rope and canvas, as well as a considerable part of their clothing*" (HR NSW).

Ralph Clark, marooned on Norfolk Island for 11 months after the sinking of the Sirius in early 1790, observed the attempts to prepare the Flax but was apparently never as optimistic as commandant King. In his journal dated 31 August 1791, Clark writes that "*about 35 men and about the Same number of women [are employed] in Cutting the flax to endeavour to bring it to perfection at Cascade Farm under a (Mr Hume) who was Sent her in one of the Ships that came here last by the Governor who Says that he understands it but for my own part I doe not think that it will ever answer the expectations of Government I am no Judge therfor cannot Say they will or they will not*" (Fidlon & Ryan 1981).

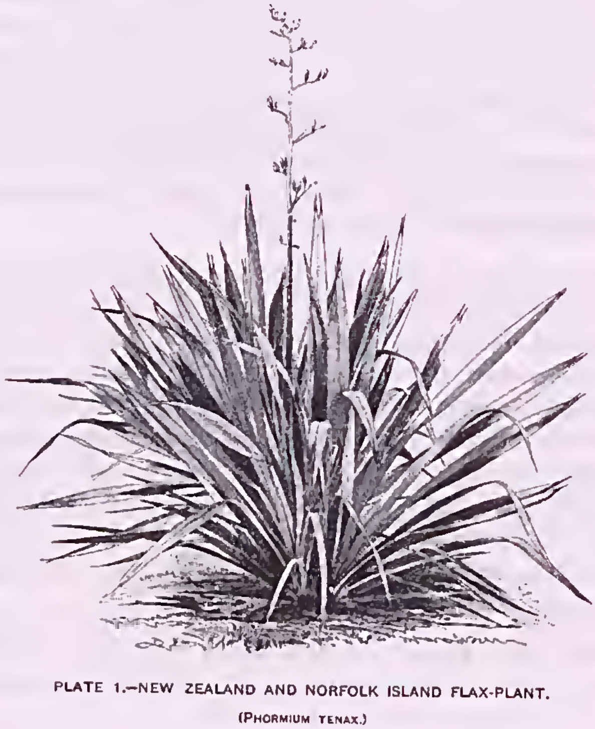
PLATE 1.—NEW ZEALAND AND NORFOLK ISLAND FLAX-PLANT.
(PHORMIUM TENAX.)

Fig. 1. Drawing of *Phormium tenax*; reproduced from Historical Records of NSW Vol. 1, Part 2, Appendix B, page 707.

All in all, the original settlement of Norfolk Island, based almost entirely on some brief observations made by James Cook in 1774, turned out to be somewhat of a failure, at least as far as the value of the materials to be obtained was concerned. The original settlement, known as the First Convict Settlement, was abandoned in 1814.

Recently, there has been a suggestion that *Phormium tenax* was brought to Norfolk Island by Polynesians prior to its discovery there by Europeans in the late 18th Century (Macphail, Hope & Anderson 2001; Coyne 2009). This paper looks critically at the evidence for and against its human introduction to Norfolk Island.

Review of the Evidence

The paper by Macphail et al. (2001) challenges the long-held view of the indigenous nature of *Phormium tenax* on Norfolk Island. Analysing pollen obtained from the swamp at Kingston on Norfolk Island, the authors endeavoured to reconstruct the previous vegetation in the area. The authors state, probably correctly, that "*the only treeless areas* [on Norfolk Island] *were the Phormium tenax covered sea cliffs*". The early records support the contention that Norfolk Island was largely covered in subtropical rainforest, with treeless areas only on the coastal cliffs around the edges of the island.

Macphail et al.'s contention that *Phormium* may not be indigenous is based entirely on the absence of *Phormium tenax* pollen in their swamp samples. One bore hole sequence was analysed for pollen, cored from the edge of Kingston swamp. No *Phormium tenax* pollen was found in any of the bore hole samples analysed, which date from the present to about 4,500 years BP. The authors state: "*it is noted that what are interpreted as relatively dry edaphic conditions would be expected to favour the local establishment of Phormium tenax* (nowhere recorded in the sequence) *had the species been present on the island in Unit C time* [i.e. c.1,000 years BP]".

Why dry conditions would favour *Phormium* if it was introduced from New Zealand is unclear. In all of the books on the New Zealand flora consulted, it is stated that the species grows in swamp conditions. The Flora of New Zealand (Moore & Edgar 1970), for example, states that the species grows "*especially in lowland swamps and intermittently flooded land*". Wehi and Clarkson (2007) note that the species is "*a well recognised element of freshwater wetlands*" and is "*most commonly in freshwater wetlands*". Although intolerant of permanent deep water, *Phormium tenax* in New Zealand thrives in very wet soils, including swampy conditions. That it grows on dry, exposed sea cliffs around Norfolk Island, but possibly not in swamps, may in fact be indicating a distinct taxon.

Macphail et al. (2001) continue: "*Nevertheless, the complete absence of Phormium tenax* (New Zealand Flax) *pollen at a site known to have been within metres of a ridge described as being covered by this plant in A.D. 1774 is difficult to explain unless Phormium was introduced onto Norfolk Island by Polynesians sometime after c.1200 and before A.D. 1774. The data greatly strengthen the case that occurrences of New Zealand Flax elsewhere on small Southwest Pacific islands such as Raoul will be due to Polynesian occupation.*"

The suggestion that the Kingston swamp is located metres from a ridge said, in 1774 (the year of Cook's discovery of the island), to be covered in the plant is not consistent with the account at the time. Cook (quoted in Hoare 1969) mentions Flax being near his landing place at Duncombe Bay on the northern and opposite side of the island to Kingston. Cook's ship did not go anywhere near the Kingston side of the island, as shown by the plot of the course of the *Resolution* by ship's master Joseph Gilbert (Hoare 1969; Beaglehole 1969). Cook makes the following single mention of *Phormium* in his journal (Beaglehole 1969): "*We found the Island uninhabited and near a kin to New Zealand, the Flax plant, many other Plants and Trees common to that country was found here …*". The journal of William Wales, Astronomer on the *Resolution*, provides a bit more information on what was seen when they landed at Duncombe Bay (Beaglehole 1969): "*Near the shores the Ground is covered so thick with the New Zealand flax-Plant that it is scarce possible to get through it … a little way in-land the woods were perfectly clear and easy to walk in.*" One suspects that the authors may have been referring to the comment by King as he landed for the first time at Slaughter Bay (Kingston) in 1788, rather than the writings of Cook: "*above this beach lay a bank ye edge of which was surrounded by ye large kind of Iris* [Flax]" (Fidlon & Ryan 1980). In any event, it is clear that Flax covered most of the coastal cliffs and ridges around Norfolk Island in 1774.

Norfolk Island shares about 33% of its indigenous flora of 182 species with New Zealand (Mills 2007). Much of the fauna, at least at the level of genus, is also shared between the two localities. In considering the distribution of several species of New Zealand origin among the islands of the south-western Pacific, Fleming (1976) writes that "*the presence of the New Zealand monocotyledon Phormium tenax* (*Agavaceae*) *at Norfolk, the Chatham and Auckland Islands … is almost an exact parallel to the three bird distributions*" discussed in the paper. Wehi and Clarkson (2007) note that morphological differences in *Phormium tenax* have been identified from different geographical localities. This includes plants from the Chatham Islands (Greenwood 1992). Some of these taxa may in future be recognised as distinct. The Norfolk Island taxon has sometimes been considered as different, e.g. Department of Environment (Australia) web site lists it as *P. aff. tenax*. Green (1979), in a paper on the phytogeography of some Norfolk Island plants, made the following comment: "*There is some undescribed differentiation which needs investigation in Phormium tenax J.R. & G. Forst., the New Zealand Flax, which on Norfolk Island is confined to damp areas on cliffs and by the sea.*" There is no mention of this differentiation in the flora of Norfolk Island (Green 1994), even though it was largely prepared by the same author.

Discussion

Peter Coyne (2009) suggests that Polynesians introduced *Phormium tenax* to Norfolk Island. Coyne's contention is based on two pieces of information; firstly, the evidence from the above pollen study by Macphail et al. (2001), and secondly the assumed absence of the species from nearby Phillip Island (6 km south of Norfolk Island) at the time of European settlement (assumed because it was not reported from there by early observers). The question then, is whether this evidence is enough to conclude that *Phormium tenax* was introduced to Norfolk Island by Polynesians? It is contended here that the evidence presented by the authors of the above papers promoting the Polynesian introduction of *Phormium tenax* to Norfolk Island is not strong and is certainly not conclusive.

Palynological and taxonomic evidence

One fact that is inconsistent with the interpretations made of the pollen analysis is that even though *Phormium tenax* has been known to be on the island since before 1774, none of its pollen was found in the top (most recent) section of the bore hole core. It does not seem to be reasonable to then surmise that because *Phormium* pollen is not present lower down the core then it was not on the island. That the top section of the core was highly modified during European times should not matter, as this species was abundant on the island at the time.

The palynology literature for New Zealand reveals that *Phormium* seldom appears in pollen diagrams. This may seem incongruous given the abundance and widespread occurrence of *Phormium* in New Zealand but the reason is apparent in a statement by McGlone (2009) "*other monocotyledonous pollen types are generally well represented in the pollen rain with the exception of Orchidaceae and Phormium, which despite bearing tall culms of large flowers, is rarely represented by more than a grain or two even when completely dominating a site.*" The assertion by Macphail et al. (2001) that the absence of *Phormium* pollen from a single core in Kingston swamp proves that it was introduced to Norfolk Island by Polynesians about 800 years BP is, in this author's view, a flawed conclusion. In their paper Macphail et al. refer to "*bias caused by preferential destruction of less robust pollen types*", but do not discuss this issue in relation to the lack of *Phormium* pollen in their analyses.

Smissen and Heenan (2007) found that plants of *Phormium tenax* on the Chatham Islands, well to the east of New

Zealand, are distinct in certain features when compared to the New Zealand material. They also found that a specimen of *Phormium tenax* from Norfolk Island was allied genetically to plants sampled from the North Island, Three Kings Islands, Poor Knights Islands and Chatham Islands, and that this group was distinct from specimens obtained from the South Island. This would be consistent with an indigenous status on Norfolk Island. The Polynesians did go to the Chatham Islands, but *Phormium tenax* from those islands is so distinct that there is no suggestion that it was introduced to those islands by Polynesians.

The natural occurrence of *Phormium tenax* on Norfolk Island is not inconsistent with the presence of that species on the Chatham Islands and proves that long distance oceanic dispersal of *Phormium* is possible. Both island groups are a long way from New Zealand; 780 km for Norfolk and 700 km for the Chathams, though the latter group is to the east of New Zealand making it easier for colonisation due to the prevailing weather systems. For Norfolk Island the Tasman Current and associated currents swirling anticlockwise around the Tasman Sea between Australia and New Zealand, may provide a long distance dispersal advantage. Sweeping up the west coast of New Zealand, the currents extend north towards Norfolk Island. Wehi and Clarkson (2007) note that seeds of *Phormium* float, and it is not beyond the bounds of possibility that seeds or other *Phormium* material capable of propagation reached Norfolk Island in the distant past via this current.

Given the above facts and the three million years that the Norfolk Island group has existed, it is not unreasonable to suggest that *Phormium* could have managed to get there. That Norfolk Island shares one third of its indigenous flora with New Zealand further strengthens this possibility. Clearly, over an extended period of time, plants can reach remote islands. Seeds can be blown by the wind, carried by birds and float across the ocean. Parts of plants capable of propagation can be floated long distances, perhaps attached to large trees or masses of vegetation washed into the sea during floods.

Polynesians did introduce bananas to Norfolk Island; these were found growing beside the creek at Arthur's Vale, not far inland from Kingston. Humans must have transported the sterile banana *Musa paradisiaca* to Norfolk. Vegetative propagation through dispersal of ramets from the most useful forms of *Phormium tenax* by Maori people has been well documented (e.g. Wehi & Clarkson 2007). There may be some relevance in that the Norfolk Island plants are said to be inferior for the purposes of weaving (M. Christian, pers. comm.). Archaeological evidence below the sand dunes behind Emily Bay at Kingston proves beyond doubt that Polynesians reached Norfolk Island. The way in which Polynesians used the island is still controversial, but it could have been on a seasonal or occasional basis; they apparently modified little of the environment of the island so were unlikely to have been long term inhabitants.

Phillip Island

On 2nd December 1788, King made a visit to Phillip Island and commented on its appearance: "*Most of the hills are covered with a thick entangled kind of reed which only wants burning to clear away 100 acres of ground, which would make a fine wheat land if not too dry*." The 'reed' is almost certainly the sedge *Cyperus lucidus*. Today, this species is rapidly colonising many of the exposed slopes and ridges of the island following the eradication of rabbits in the 1980s (Mills 2009), and is likely to reflect the original vegetation cover of Phillip Island.

Even if *Phormium* was absent from Phillip Island in 1788, and this cannot be established beyond doubt, it does not necessarily provide evidence that the plant was introduced to Norfolk Island. There are numerous reasons why the species was not mentioned as occurring on or was originally absent from Phillip Island. *Phormium* may have gone unnoticed and/or un-reported by King and other early observers because it was only growing on the basalt dominated south-western corner of the island or perhaps it was not readily seen amongst the dense growth of *Cyperus lucidus*. If present, Flax was not likely to have been exploited on Phillip Island (and hence not mentioned as being there), because it was so abundant on Norfolk Island. Permanent habitation never happened on Phillip Island because of the lack of fresh water. On Phillip Island *Phormium* may simply have been too uncommon to attract comment.

The absence of any mention of *Phormium* on Phillip Island is tenuous evidence in favour of it not being there in 1788; it is even a more tenuous argument to then assume it was also absent from Norfolk Island. Few botanists went to that island and no one made an extensive list of the plants found there (Mills 2009), not even Allan Cunningham who visited in 1830 made a complete list. Since the removal of rabbits from Phillip Island 20 years ago, *Phormium* has colonised the same habitats there in which it grows on Norfolk Island, namely exposed sea cliffs.

Conclusion

At this point, we cannot be sure that *Phormium tenax* is indigenous to Norfolk Island. Hints that it may be indigenous include observations that the Norfolk Island plants are different in several ways to the New Zealand plants (Green 1979, M. Christian, pers. comm.). Secondly, *Phormium* grows in a quite distinct habitat on Norfolk Island, exposed coastal cliffs, that appears to be quite natural; it apparently does not grow in swampy conditions as it commonly does in New Zealand. Thirdly, it is said that the Norfolk Island plants are inferior for the purposes of weaving, so why would Polynesians introduce that form of the plant? That the species can successfully cross hundreds of kilometres of ocean and colonise remote islands is evidenced by its presence on the Chatham Islands.

On balance, I do not believe that the available evidence yet places us in a position to know conclusively one way or another whether *Phormium tenax* is indigenous on Norfolk Island. Plants may or may not have been brought to Norfolk Island by Polynesians; certainly, it was an important plant to their economy and culture. However, we need firm evidence of its introduction before it can be accepted as fact. On the available information, it seems more likely that *Phormium tenax* is indigenous to Norfolk Island. Detailed taxonomic and genetic studies may show the Norfolk Island plants to be different enough from those found in New Zealand to be taxonomically distinct and therefore most likely to be indigenous.

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The cushion plants of lowland southern Australia

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Abstract: A preliminary analysis has recorded the cushion lifeform in 60 taxa from lowland southern Australia (i.e. latitudes south of 26° S) encompassing six morphological forms from open, non-peat-accumulating species (58 taxa) to hard, dense cushions more typical of alpine and subalpine areas (2 taxa). Only two species appear to be obligate cushions. All but six cushion-forming species are endemic to southern Western Australia. Most species occur in the Transitional Rainfall Zone rather than the High Rainfall Zone or the more arid interior, with only one species being endemic to the arid zone.

In Western Australia cushion-forming species occur on exposed coasts, granites, edges of salt lakes and sandplains; almost half of the species also commonly occur across a number of other habitat types. The few plant communities dominated by cushion plants are generally restricted to small areas of a specific habitat type such as *Borya* herblands on shallow soils around outcropping granites. Lowland cushion species in Western Australia do not appear to be restricted to the most stressful habitats.

***Cunninghamia* (2009) 11(2): 177–184**

Introduction

Cushion plants are a distinctive lifeform originally treated by some authors as being from alpine areas (e.g. Raunkiaer 1934), but also occurring in subalpine areas and on subantarctic islands (Gibson & Kirkpatrick 1985) and in various lowland areas with a range of climates other than subantarctic ones (Godley 1978). Despite work on lowland species in the Mediterranean and North Africa (e.g. Quezel 1967, Nimis 1981) little recent attention has been given to lowland cushion species. In Australia, as long ago as 1906, Diels drew attention to lowland Western Australian cushion plants in Boryaceae, Goodeniaceae, Fabaceae and Sterculiaceae (Diels 1906; translated 2007) but this has been overlooked by later workers. This paper brings together the little that is known about lowland cushion plants in the southern Australian vascular flora.

A precise definition of the term cushion plant is difficult (Raunkiaer 1934, Gibson & Hope 1986). Here, we will use the following: cushion plants are chamaephytes or hemicryptophytes that, growing singly, take on a hemispherical or subhemispherical shape due to the close branching of their shoots and their short internodes. This combines the definitions given by Gibson and Kirkpatrick (1985) and Gibson (1991). The hemispherical shape provisions allow mat plants to be excluded (see also Foweraker 1917). The leaves are small (Godley 1978), which allows the shoots to be very closely compacted (Foweraker 1917). It is implied in the definition above that the margins of the shoot canopy normally extend downwards to reach ground level. As defined here, cushion plants form a continuum from hard, compact species that accumulate peat within their shoots to soft, loose, non-peat-accumulating species. Examples of intergradation between the various types defined below are common and some species only occasionally take on a cushion form (Rauh 1939).

In Australasian alpine and subantarctic areas, cushion plants are known in many different habitats, from 'bogs to shattered rock and from snowpatch to herbfield' (Gibson & Hope 1986). They are also common in similar habitats in the paramo, altiplano and alpine regions of the north, central and southern Andes (Bosman *et al.* 1993, Cavieres *et al.* 2002, Earle *et al.* 2003). This habitat range can be extended by examining the scattered Northern Hemisphere data from lowland areas, e.g. *Anabasis aretioides* Moq. et Coss. (Chenopodiaceae) occurs in the Sahara Desert (Hauri 1912) and *Centaurea horrida* Badaro (Asteraceae) occurs on Sardinian sea-cliffs exposed to strong, salt-laden winds (Mameli *et al.* 2008). The latter is one of a group of lowland Mediterranean cushion plants found in 'thorny-cushions' vegetation (Nimis 1981). This group includes species of *Anthyllis, Astragalus, Genista* (all Fabaceae), *Stachys* (Lamiaceae) and *Sarcopoterium* (Rosaceae) (Nimis 1981).

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Methods

Using the definition given above, a list of cushion plants in southern Australia (i.e. latitudes south of 26° S) was developed using literature searches, by searching the collections database at the Western Australian Herbarium (PERTH) for specimens having the word 'cushion' in the plant description field and with input from the researchers listed in the acknowledgments. The resulting list should not be regarded as comprehensive and should be viewed as a list of species which can occur as cushions but do not always take on that form. Some species, such as *Schoenus calcatus*, we regard as obligate cushions but many others are not.

The most detailed classification of the types of cushion plants is that of Rauh (1939), published in German. We applied his basic typology here except that we excluded his 'annual and biennial cushions' and his 'tree cushions' categories. We also excluded mat plants that never form cushions or raised mounds. For some types, Rauh uses the German word 'kugel' which strictly translates as 'spherical'. Here, we translate it as 'hemispherical' to better reflect cushion shape. Similarly, we translate 'flach' as 'low' rather than 'flat' given that Rauh uses 'flach' to include subhemispherical plants.

Distributional information for Western Australian species, based on the Interim Biological Regionalisation of Australia (IBRA) version 5.1 (Cummings & Hardy 2000), is available from the collections database at PERTH. Summary figures were compiled using all collections of each species. Typical habitat information for these species was compiled from the collections database and field observations by the authors. Species nomenclature follows current usage at PERTH unless species authors are given (Western Australian Herbarium 1998–). Taxa that have not yet been formally named are referred to by standardised phrase names.

Results

At least 60 southern Australian vascular plant species in 14 families fall within the definition of cushion plant given above (Table 1). The number of genera per family ranged from one to three. The genera with most cushion species are *Acacia* (9 species), *Andersonia* and *Stylidium* (8 taxa), *Borya* (6 species) and *Hibbertia* (5 taxa). All but six of these 60 species are endemic to southern Western Australia (Table 1).

Rauh types

Using the translations given above, the Rauh types represented on our list are 'shrub cushions', 'turf cushions', 'radial-hollow-hemispherical cushions', 'radial-low cushions' (both hollow and solid types) and 'rosette cushions'.

Leucophyta brownii is the sole representative of Rauh's 'shrub cushion' type (generally greater than 50 cm tall, taking on an open, hemispherical shape). This species is typical of coastal habitats, where the hemispherical shape is common.

Rauh's 'turf cushions' are a broad category primarily defined by the non-persistence of a tap root. They are represented in our list by the monocot taxa, with the exception of *Lomandra mucronata* (Table 1). All six *Borya* species and *Schoenus* sp. Cape Riche Cushion (G.J. Keighery 9922) occur as soft, hemispherical, non-peat-accumulating cushions with extensive adventitious roots from old leaf bases. *Schoenus calcatus,* in contrast, forms a solid, dense cushion that accumulates peat within its canopy and has similar morphology to the hard, bolster species of southern hemisphere alpine areas (Gibson & Kirkpatrick 1985).

Schoenus calcatus and five of the *Borya* species endure extended dry periods by altering the structure of their leaf cells, which change colour to orange or yellow (Table 1). With the onset of winter rains the leaves quickly revert to green and their functions are restored (Gaff 1981, George 2002a). These have previously been referred to as resurrection plants (Gaff 1981). George (2002a, 2002b) has recently documented that diallagy (colour change over dry periods) is much more widespread than previously appreciated in the Western Australian flora. In contrast, *Borya laciniata*, which only occasionally forms cushions, is a drought-avoider which sheds its leaves over the dry summer months (Churchill 1987).

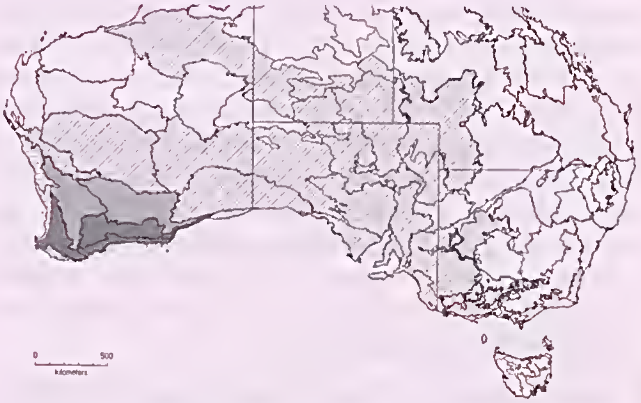

Fig. 1. Map of distribution of lowland cushion species across southern Australia by IBRA regions. Counts are derived from all collections of species that are known to form cushions, Western Australian records from the Western Australian Herbarium, other records from the Australia's Virtual Herbarium. Diagonal cross hatching indicates 1–10 species per region; horizontal cross hatching indicates 11–20 species per region; light grey solid fill indicates 21–30 species per region; and dark grey solid fill indicates 21–38 species per region.

The 'radial-hollow-hemispherical cushion' type is represented by 14 species; 11 epacrids (*Andersonia*, 7 species; *Astroloma*, 4 species), *Ptilotus helichrysoides* (Amaranthaceae), *Argentipallium tephrodes* (Asteraceae) and *Lomandra mucronata* (Dasypogonaceae).

The most common cushion type is the 'radial-hollow-low cushion', represented by 30 species (Table 1), some of which can reach diameters of greater than a metre (e.g. *Acacia pulviniformis*).

Seven of the eight *Stylidium* taxa form small, 'rosette cushions', while *Stylidium pulviniforme* forms small 'radial-solid-low cushions'.

Distribution

The distribution of lowland cushion species is not uniform across southern Australia; 58 of the 60 taxa are recorded from Western Australia, with only four of the Western Australian species extending into other States. Even within Western Australia, lowland cushions' distributions are not uniform (Fig. 1) and they are more concentrated in the South West Floristic Region (an area of Mediterranean climate) than the arid inland. Within the South West, cushion species are more common in the Transitional Rainfall Zone (300–600 mm rainfall) than either the High Rainfall Zone along the south and west coast or the more arid interior (zones as defined by Hopper & Gioia 2004).

The western and southern coastal areas have 50–60% of the numbers of species occurring in the Transitional Rainfall Zone, while in the more arid regions of Western Australia richness drops off very rapidly with only two species (*Hemichroa diandra* and *Ptilotus helichrysoides*), extending into the Great Victoria Desert.

Frankenia muscosa J.M.Black (Fig. 2) is the only strictly arid zone endemic in Table 1, occurring in sites with a mean annual rainfall of about 140 mm in the Northern Territory and South Australia.

Nine taxa (*Andersonia* sp. Mitchell River (B.G. Hammersley 925), *Hibbertia hibbertioides* var. *pedunculata*, *Schoenus* sp. Cape Riche Cushion (G.J. Keighery 9922), *Scholtzia* sp. Kalbarri (N. Hoyle 623), *Stylidium amabile*, *Stylidium coroniforme* subsp. *amblyphyllum*, *Stylidium coroniforme* subsp. *coroniforme*, *Stylidium ferricola*, *Stylidium* sp. Glabrous inflorescence (R. Davis 7917)) have quite restricted distributions, being only recorded from single IBRA regions in Western Australia. One species, *Borya mirabilis* Churchill, is restricted to a single location in the Grampians National Park in western Victoria (Coates 2000). The eight most common species (*Astroloma ciliatum*, *Astroloma pallidum*, *Borya constricta*, *Borya sphaerocephala*, *Frankenia pauciflora*, *Hibbertia acerosa*, *Lechenaultia tubiflora*, *Stylidium piliferum*) were recorded from between seven to 10 IBRA regions.

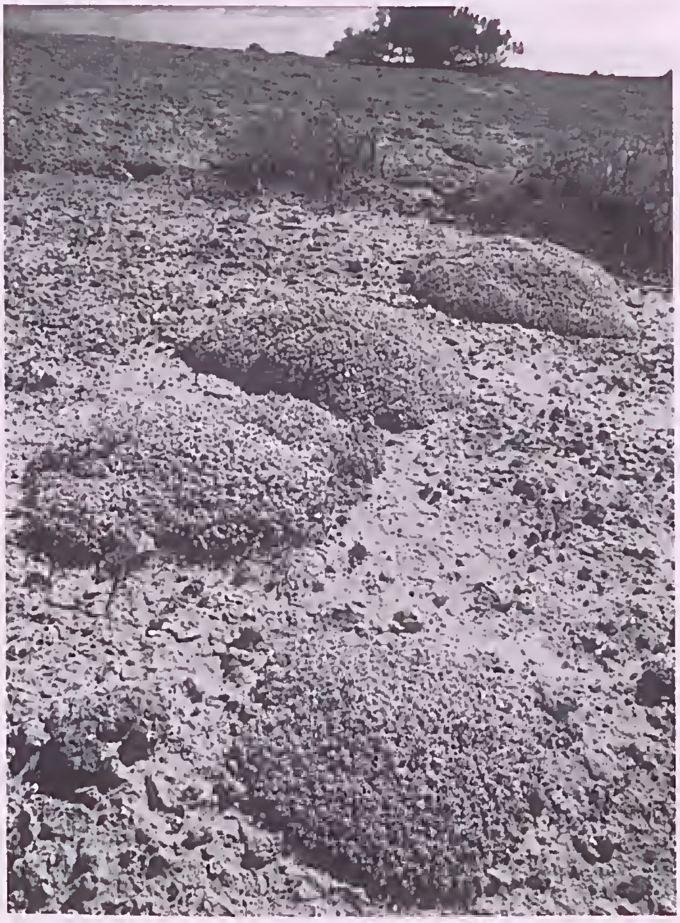

Fig. 2. Cushion plants of *Frankenia muscosa* 10cm high near Dalhousie Springs, South Australia. Photo by Reg Morrison; first published in van Oosterzee (1991).

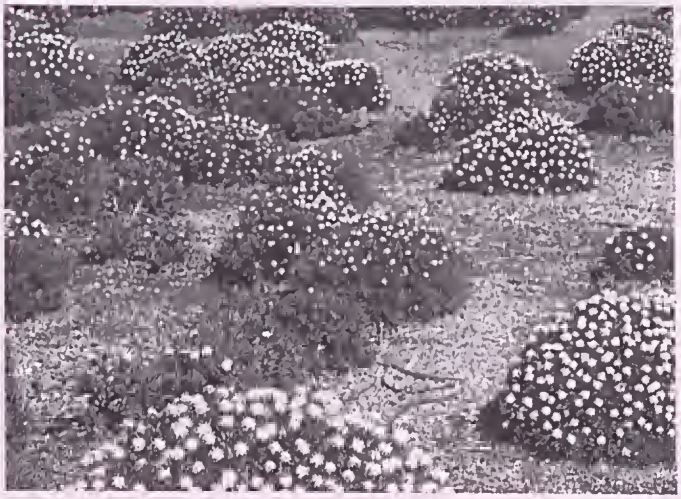

Fig. 3. Cushion plants of *Borya constricta* 10cm high on shallow granitic soil, Peak Charles National Park, SW of Norseman, Western Australia. Photo by Bruce Fuhrer.

Table 1. Cushion type, habitat and distribution for lowland cushion plants in the southern Australian vascular flora.

Cushion types: RHH = 'radial-hollow-hemispherical'; RHL = 'radial-hollow- low'; RSL = 'radial-solid-low'; R = 'rosette'; SC = 'shrub'; T = 'turf'.
Habitat: the most typical habitats are listed. Where blank, the species occurs over a range of habitats.
Distribution: endemic to south-western Australia unless otherwise indicated in the Notes column by these codes: NSW = New South Wales; NT = Northern Territory; SA = South Australia; T = Tasmania; V = Victoria; WA = Western Australia. Some common names are given in inverted commas in the Notes column.

Family/Species	Type of cushion	Habitat	Notes	References
Monocots				
Boryaceae				
Borya constricta	T	Granite	A resurrection plant.	George (2002b); Fig. 3
B. laciniata	T	Granite	Only occasionally a cushion; drought-avoider with deciduous leaves.	George (2002b)
B. longiscapa	T	Granite	A resurrection plant	George (2002b)
B. mirabilis	T	Sandstone outcrop	V. A resurrection plant. 'Pincushion Lily' Threatened flora.	Coates (2000)
B. nitida	T	Granite	A resurrection plant. 'Pincushions'	Churchill (1987)
B. sphaerocephala	T	Granite	A resurrection plant.	George (2002b)
Cyperaceae				
Schoenus calcatus	T	Sand	A probable resurrection plant. 'Newdegate Cushion'	Wilson (1997), George (2002b)
S. sp. Cape Riche Cushion (G.J. Keighery 9922)	T	Sand	'Cape Riche Cushion'	
Dasypogonaceae				
Lomandra mucronata	RHH	Granite, Sand		
Dicots				
Amaranthaceae				
Hemichroa diandra	RHL	Coastal, Saline	NSW, SA, V, WA.	
Ptilotus helichrysoides	RHH			
Asteraceae				
Argentipallium tephrodes	RHH	Saline		
Leucophyta brownii	SC	Coastal	SA, V, T, WA.	
Chenopodiaceae				
Roycea pycnophylloides	RHL	Saline	Threatened flora	
Dilleniaceae				
Hibbertia acerosa	RHL	Granite		
H. diamesogenos	RHL	Granite		
H. hibbertioides var. *pedunculata*	RHL			
H. priceana	RHL		Threatened flora	
H. turleyana	RHL	Sand		
Ericaceae				
Andersonia caerulea	RHH	Sand	One form of variable species.	
A. grandiflora	RHH	Sand		
A. geniculata	RHH			
A. setifolia	RHH			
A. sp. Mitchell River (B.G. Hammersley 925)	RHH			
A. sprengelioides	RHH	Granite, Coastal		
A. virolens	RHH			

Family/Species	Type of cushion	Habitat	Notes	References
Astroloma ciliatum	RHH			
A. compactum	RHH			
A. pallidum	RHH			
A. sp. Tutanning (A.S. George 7779)	RHH			
Fabaceae				
Eutaxia acanthoclada	RHL			
Kennedia microphylla	RHL		Only occasionally cushion.	Diels (1906)
Pultenaea purpurea	RHL		One form of variable species.	Figs. 4 & 5
Frankeniaceae				
Frankenia muscosa	RHL	Saline	NT, SA. Species name means 'moss-like'.	Fig. 2
F. pauciflora	RHL	Coastal, Saline	SA, T, V, WA. Occasionally cushion, not restricted to coastal areas.	
F. sessilis	RHL	Saline	SA, V, WA.	
Goodeniaceae				
Lechenaultia formosa	RHL	Granite, Sand		
L. pulvinaris	RHL	Sand	The species name means 'cushion-like'.	
L. tubiflora	RHL	Granite, Sand		
Scaevola crassifolia	RHL	Coastal		
S. humifusa	RHL	Saline	Not restricted to saline areas.	
S. pulvinaris	RHL		The species name means 'cushion-like'.	
Mimosaceae				
Acacia acanthaster	RHL	Granite		
A. brachyclada	RHL			
A. concolorans	RHL			
A. crassuloides	RHL			
A. lachnophylla	RHL			
A. poliochroa	RHL			
A. pulviniformis	RHL		The species name means 'cushion-like'.	
A. pusilla	RHL			
A. sorophylla	RHL	Saline	Not restricted to saline areas.	
Myrtaceae				
Eremaea fimbriata	RHL			
Scholtzia sp. Kalbarri (N. Hoyle 623)	RHL	Coastal, Sand		
Stylidiaceae				
Stylidium amabile	R			Wege & Coates (2007)
S. ciliatum	R			
S. coroniforme subsp. amblyphyllum	R			Wege & Coates (2007)
S. coroniforme subsp. coroniforme	R		Threatened flora	Wege & Coates (2007)
S. ferricola	R			Wege *et al.* (2007)
S. piliferum	R			
S. pulviniforme	RSL	Sand	The species name means 'cushion-like'.	
S. sp. Glabrous inflorescence (R. Davis 7917)	R	Sand		

Habitat

The landscapes of the South West of Western Australia have developed on Archaean granites of the Darling Plateau that have undergone little mountain building since the Permian glaciations and as a result have undergone an extended period of weathering. This has resulted in Tertiary–Quaternary laterites and sandplains on the uplands and duplex soils in the broad valleys with sluggish, generally saline drainage lines, especially in the east (Gibson *et al.* 2004). Quaternary aeolian sands occur along parts of both the west and south coasts.

The typical distribution of lowland cushion species across this landscape can be considered in the following groups, although individual species generally occur across a number of habitat types.

Species occurring on exposed coasts

There are at least six species of cushion plants found in sites exposed to high levels of wind and salt spray in southern Australia (Table 1); a habitat which is shared with many of the 'thorny cushion' shrub species from the Mediterranean (Nimis 1981).

Of the six cushion species occurring along the coast only *Scaevola crassifolia* and *Leucophyta brownii* are restricted to that habitat, while *Hemichroa diandra* becomes restricted to this habitat in northern Western Australia. Both *Hemichroa diandra* and *Frankenia pauciflora* also occur on saline soils and around salt lakes in addition to occurring in coastal situations.

Species occurring on saline or subsaline soils

This group comprises the three *Frankenia* species, *Hemichroa diandra*, *Roycea pycnophylloides*, *Acacia sorophylla*, *Argentipallium tephrodes*, and *Scaevola humifusa*, although these last three species are not restricted to this habitat. (Table 1). *Roycea pycnophylloides* is only known from salt lakes in the central wheat belt and is listed as Threatened flora.

Species occurring on non-saline arid zone sites

A single species, *Ptilotus helichrysoides*, extends into dry non-saline desert sites, in this case the Great Victoria Desert. Similarly, a range of cushion plant species can be found in non-saline parts of the Sahara Desert (Hauri 1912, Quezel 1967).

Species occurring on granites

Sixteen species occur on granitic soils but none are restricted to this habitat; they also occur on sandy or lateritic substrates. Some of the few plant communities in Western Australia dominated by cushion plants are the *Borya* herblands growing on the shallow soils on the edge of granite aprons. These communities, while restricted in size, are widespread around the granite outcrops of the South West (Fig. 3). As with the majority of Western Australian *Borya* species, the rare Victorian species, *Borya mirabilis*, is a resurrection plant. Its single population occurs on a ferruginous sandstone outcrop which would suffer summer water stress similar to the granite habitats in the west.

Species occurring on sandplain or sand over limestone

A further nine species are recorded as occurring on sandplain or sand over limestone:– *Andersonia caerulea, Andersonia grandiflora, Hibbertia turleyana, Lechenaultia pulvinaris, Schoenus calcatus* , *Schoenus* sp. Cape Riche Cushion (G.J. Keighery 9922), *Scholtzia* sp. Kalbarri (N. Hoyle 623), *Stylidium pulviniforme, Stylidium* sp. Glabrous inflorescence (R. Davis 7917). A further three species, *Lechenaultia formosa, Lechenaultia tubiflora* and *Lomandra mucronata* are common on sand as well as granite substrates.

The remaining 28 species are not easily categorised, occurring over a range of habitat types (Table 1).

Discussion

Rauh's (1939) comprehensive classification covers 12 basic cushion types including trees, shrubs, annual and perennial herbs, graminoids and mosses. These morphological types encompass soft, loose, non-peat-accumulating species to hard, compact species that accumulate peat within their canopies ('bolster' cushions of Gibson & Kirkpatrick 1985), with intergrades being common. Alpine bolster species would typically fall into his 'radial-solid-hemispherical cushion' ('Radialvollkugelpolster'), 'radial-solid-low cushion' ('Radialvollflachpolster') and dense forms of his 'turf cushion' ('Rasenpolster').

We recorded only two hard, compact, peat-accumulating cushion species from lowland southern Australia, *Schoenus calcatus* ('turf cushion') and *Stylidium pulviniforme* ('radial-solid-low cushion'), as well as 7 non-dense 'turf cushions', 13 'radial-hollow-hemispherical cushions', 30 'radial-hollow-low cushions', 7 'rosette cushions' and one 'shrub cushion' type. We did not find any 'radial-solid-hemispherical cushions' which are typically alpine. The seven non-dense, 'turf cushions' were all monocots and did not accumulate peat, suggesting that these should probably be treated as a separate subtype. The most common features of the lowland cushions (with the exception of *Schoenus calcatus* and *Stylidium pulviniforme*) were that they did not accumulate peat within their canopies and that both cushion and non-cushion forms were common within the same species (Figs. 4 & 5).

While we record cushion plants in 14 different families from southern Australia (Table 1), it is likely that some families are genetically more likely to develop cushion morphology than others. For example, Ericaceae (previously Epacridaceae) has the largest number of species (11) and also figures prominently in lists of cushion species from elsewhere (Gibson & Hope

1986). Similarly, species of Cyperaceae and Stylidiaceae commonly form cushions in alpine and subalpine areas in the Australasian region (Gibson & Hope 1986). Frankeniaceae (three species in Table 1) includes the cushion plant *Anthobryum triandrum* (Remy) Surgis from NE Argentina, which occurs in saline sites at altitudes of 3 400–4 700 m (Ruthsatz 1978) and was formerly treated as a *Frankenia* (the generic name translates as 'flowering moss'). Diels (1906) identified one species of Sterculiaceae, *Rulingia cuneata,* as forming cushions in Western Australia, no collection of this species could be located that exhibited that form.

Damage from salt spray causes many shrub species to share some characteristics with cushion plants, namely profuse shoot branching and a dense, compact canopy (Boyce 1954). Most of these species exhibit asymmetric shoot growth forms which are not hemispherical or subhemispherical (Boyce 1954), excluding them from the cushion category; further work is needed on the extent to which salt spray can contribute to cushion morphology.

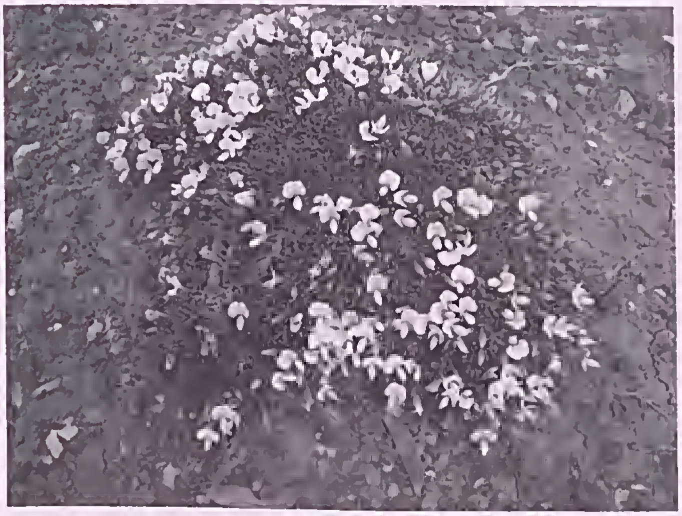

Fig. 4. Cushion plant of *Pultenaea purpurea* 10cm high on shallow sandy clay loam with metasedimentary surface fragments, Ravensthorpe Range, Western Australia. Photo by Adrienne Markey.

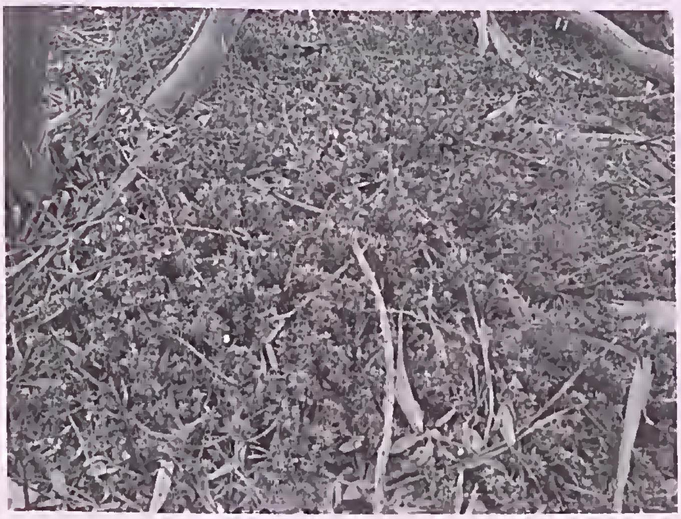

Fig. 5. Non cushion form of *Pultenaea purpurea* 30cm high growing under tall mallee shrubland on a sandy clay loam, Ravensthorpe Range, Western Australia. Photo by Adrienne Markey.

Cushion plants were found in 60 species across southern Australia but our finding that lowland species capable of forming cushions are heavily concentrated in Western Australia needs further validation, since only the collections at PERTH were used to identify cushion-forming species. Similar analyses of the collections at the other State herbaria are also needed.

Most cushion species within southern Western Australia are found in the South West Floristic Region, an area with a Mediterranean climate. Within the South West, cushion-forming species are concentrated in the Transitional Rainfall Zone, a very species rich area where explosive speciation in the woody perennial taxa has occurred in response to climatic perturbations in the late Tertiary and Quaternary (Hopper *et al.* 1996, Hopper & Gioia 2004).

Cushion plants in Western Australia rarely dominate the vegetation in which they occur, however, where this happens it is at a local scale in habitats of significant stress (e.g. *Borya* herblands on granite aprons, *Roycea* herblands on saline soils and *Scaevola* shrubland on exposed coasts). Cushion dominated vegetation in Western Australia supports Korner's (2003) view that cushions are typical of stressed habitats as has been reported in alpine areas. However the wider distribution patterns of Western Australian lowland cushion species are quite variable and are at odds with the view that cushion species are restricted to extreme sites. While some occur in restricted habitats or habitats where environmental stress would be considered high, other species occur across a wide variety of habitats as components of species-rich shrublands with at least half of the cushion-forming species occurring as minor components of species-rich shrublands on a variety of sandplain, laterite and clayey substrates.

Typically, cushion taxa in southern Western Australia occupy a variety of habitats coexisting in species rich shrublands with a number of other lifeforms, in contrast to both alpine (Korner 2003) and other lowland cushion species (Nimis 1981).

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Vegetation changes in Hexham Swamp, Hunter River, New South Wales, since the construction of floodgates in 1971

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Abstract: Hexham Swamp (32° 52' S, 151° 41' E), the largest wetland on the floodplain of the lower Hunter River, New South Wales (ca. 2500 ha in area), historically supported extensive areas of estuarine wetlands. Substantial vegetation changes have occurred following the 1971 construction of floodgates on the main creek draining the swamp. Previous areas of mangroves have been reduced from180 ha to 11 ha, and saltmarsh from 681 ha to 58 ha. *Phragmites australis* reedswamp has expanded from 170 ha to 1005 ha. Much of the mangrove loss (ca. 130 ha) was a result of clearing, and the remainder has gradually died off. The factors contributing to the dieback are likely to be a combination of drying of the soil, and, at times, waterlogging. Field sampling indicates that a reduction in soil salinity has been an important factor initiating successional change from saltmarsh to *Phragmites* reedswamp. The data also suggest that increased waterlogging has been an important factor in vegetation change. The initial effect of the floodgates was expected to have been a drying of the swamp, followed over time by an increasing wetness(floodgates and associated drainage are generally intended to reduce the flooding of wetlands). The apparently paradoxical result is likely to have resulted from occlusion of drainage lines by sediment and reeds.

***Cunninghamia* (2009) 11(2): 185–194**

Introduction

As elsewhere in the world, estuarine wetlands in eastern Australia have historically been seen as opportunities for expansion of urban, industrial and agricultural activities. While the first two typically result in the complete loss of a wetland through landfill, agricultural activities often allow the retention of the wetland, albeit in a modified condition more conducive to agriculture. The desired agricultural condition, involving a reduced salinity and decreased wetness, is typically achieved through the restriction of tidal flows and construction of drains. Restricting tidal flows into, and draining estuarine wetlands alters hydrology and sediment chemistry, which in turn may affect plant community composition (MacDonald 2001, McGregor 1980, Pressey and Middleton 1982, Roman *et al.* 1984).

The cessation or reduction of tidal inundation typically leads to drying of wetlands. This drying can be in the form of less frequent inundation, and a consequent drop in groundwater levels (Portnoy and Giblin 1997, Roman *et al.* 1984). However sometimes there may be an increase in wetness when levees or other fixed structures (designed to restrict incoming tidal flows or floodwaters), also act as dams preventing or retarding the outflow of stormwater. There are reported cases where structures have had an intentional or inadvertent damming effect leading to the dieback of mangroves and other estuarine wetland vegetation (Gordon 1988, Jimenez and Lugo 1985). Another factor potentially contributing to ponding in restricted wetlands is the occlusion of drainage channels by plant growth and sediment build-up (Turner and Lewis 1997). This occurs as a result of reduced water flow velocities in the channels after restriction of tidal flows.

Drying of wetland soils can alter soil chemistry, both in the short and long term. Oxidation of sulphide compounds, can lead to the development of acids which lower soil pH and can affect the availability of nutrients. Over the longer term, oxidation of sulphide compounds removes toxic sulphides from the soils, allowing establishment and growth of plants that may be sensitive to sulphides, although this may take many decades (Portnoy and Giblin 1997).

The most obvious change in soil and water chemistry is the reduction in salinity when tidal inundation on previous

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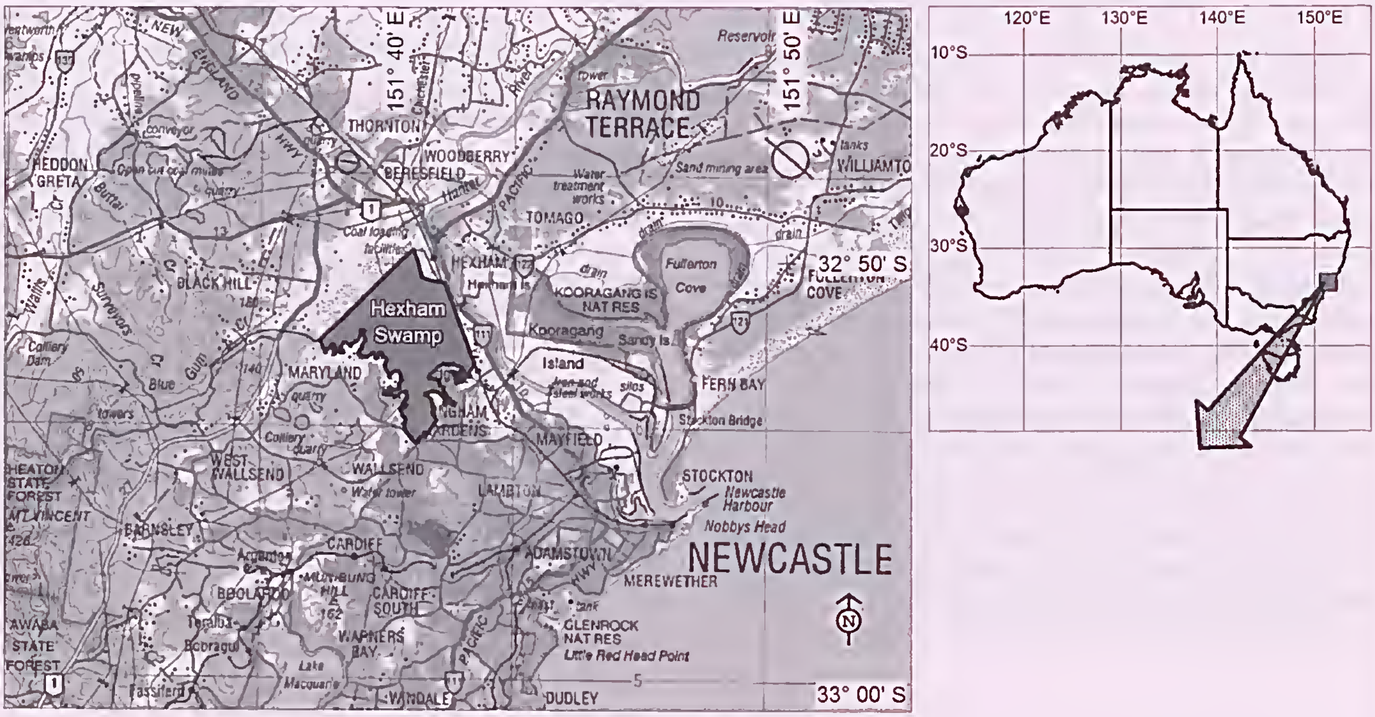
tidal flats is reduced. Inundation of these areas is then due primarily to direct precipitation and catchment runoff. This freshwater input leaches salt from the upper layers of the soil down the soil profile and/or off the marsh as surface runoff. As a consequence, tidally restricted wetlands have a lower soil salinity than unrestricted wetlands (Burdick *et al.* 1997, Roman *et al.* 1984).

The changed physical and chemical environment following tidal restriction allows plant species to establish that would otherwise find the estuarine wetland environment toxic. These plants can have a competitive advantage over the original vegetation and gradually displace it (Brockmeyer *et al.* 1997, MacDonald 2001, Minchinton and Bertness 2003, Roman *et al.* 2002, Warren *et al.* 2002). The change in vegetation combined with hydrological changes, in turn alters available habitats for estuarine fauna (Pollard and Hannan 1994, Pressey and Middleton 1982).

Hexham Swamp (32° 52' S, 151° 41' E) (Figure 1), the largest wetland on the floodplain of the lower Hunter River, occurs on the backplain of the Hunter River, approximately 10 km upstream from its mouth at Newcastle harbour, between the natural levee of the south arm of the Hunter River and the low hills along the south edge of the floodplain (Winning 1996). It has an area of approximately 2500 ha, about 900ha of which lie within the Hunter Wetlands National Park (NSW National Parks & Wildlife Service 1998). The study area for this study (approximately 1900 ha) was that part of Hexham Swamp that was covered by the Hexham Swamp Rehabilitation Project (Figure 1) and excluded heavily grazed land in the northwest (Haines *et al.* 2004). While it is a floodplain wetland geomorphologically, prior to construction of floodgates Hexham Swamp was subject to tidal inflows via Ironbark Creek and its tributaries.

Hexham Swamp is included in the *Directory of Important Wetlands in Australia,* and is listed on the Register of the National Estate as part of the Hunter Estuary Wetlands (Environment Australia 2001) which recognises the importance of the large size of Hexham Swamp and the value of the Hunter Estuary Wetlands to wetland biota, while acknowledging the changes resulting from the construction of floodgates on Ironbark Creek (Department of Environment Water Heritage and the Arts 2003).

Williams and Watford (1997) identified over 4000 structures influencing tidal flows in New South Wales, including 176 floodgates on the Hunter River and its tributaries. Floodgates are structures intentionally constructed to prevent or restrict tidal flows, but may also control floodwaters. The construction of floodgates is often part of a works program including the construction of levees, and drains upstream of the floodgates to increase drainage of the upstream environment (Evans 1983, Giannico and Souder 2005, Pressey and Middleton 1982, Williams and Watford 1997). While the Hexham Swamp floodgates were constructed as part of the Hunter Valley Flood Mitigation Scheme, there is evidence that the works proposed for Hexham Swamp were driven as much by agricultural improvement as by flood mitigation. The Hexham – Minmi Swamp Salinity and Drainage Survey, the first study proposing works, was initiated by submissions from landholders concerned about the effects of salinity and poor drainage on the agricultural value of the land, and



Base map: Newcastle S156-02 1:250 000 topographic map (NATMAP 1996).

Fig. 1. Location of Hexham Swamp study area.

suggested that improved pasture crops, vegetables and dairying would be viable in Hexham Swamp after drainage and a gradual reduction in salinity. The Hexham Swamp floodgates (completed in 1971) comprise eight 2.13m x 2.13m cells on Ironbark Creek, the main creek draining Hexham Swamp. While allowing a small amount of tidal interchange in Ironbark Creek (one floodgate was left open by 15cm), the floodgates led to effective cessation of overbank tidal flooding from Ironbark Creek within Hexham Swamp (Winning 1996) leading to significant temporal changes in vegetation in Hexham Swamp. This study investigated the changes in vegetation that have occurred following the construction of floodgates and drains in Hexham Swamp, and sought to describe and, as far as possible, quantify those changes.

Methods

Vegetation mapping

Changes in vegetation were identified and described using aerial photography. The 'existing' condition was interpreted from 2004 colour aerial photography, and the pre-floodgate condition from 1966 black and white aerial photography. Contact prints were scanned at 300 dpi which resulted in effective digital mapping scales using MapInfo 7.8 of approximately 1:7000 and 1:12000, respectively. Interpretation of the existing vegetation was supported by extensive ground truthing during 2005. Pre-floodgate mapping was interpreted with the assistance of historical documents including vegetation maps prepared relatively soon after the floodgates were constructed (Briggs 1978, Dames & Moore 1978), Crown survey plans (for land grants, utility corridors, etc.) and anecdotal descriptions. A digital elevation model was constructed in MapInfo 7.8 from spot heights derived from a 1968 photogrammetric survey (NSW Public Works Department 1968).

Field sampling

Vegetation sampling sites in Hexham Swamp have been recorded more or less continuously since 2000 (some sites as early as 1997). In 2005 there were 335 sites along 53 transects that were (and continue to be) sampled every three months. Sample sites were located at 10m intervals with five or ten (in one case 15) sites per transect. Each sample site was a 2m x 3m plot with plant species abundance recorded as the frequency of occurrence (rooted in the quadrat) in six 1m x 1m quadrats. When surface water was present at sampling times, the depth and salinity of this water was recorded. Water depth and surface water salinity data are generally available for samples between and including June 2002 and November 2004. A small number of sites have standing water salinity data from March 1997. Water depth was recorded using a graduated PVC pipe with a flat base (ca. 2cm x 4cm) to limit sinking into the soft substrate. Standing water salinity was measured to the nearest 0.1ppt (gL^{-1}) using hand-held salinity meters (Cyberscan 200 meter and Hanna Dist 2 meter, at different times) calibrated to 1382ppm (mgL^{-1}) using Hanna standard solution H17032. A one-off sample of soil was collected at each site in January 2003, when the whole swamp was dry, for analysis of soil salinity. Soil salinity was measured indirectly using the standard 1:5 w/v soil to water ratio method ($EC_{1:5}$) (Rayment and Higginson 1992) with a conversion factor used to approximate saturated paste electrical conductivity (EC_e) (Slavich and Petterson 1993). $EC_{1:5}$ is a measure of the total quantity of soluble salts per unit weight of soil not per unit volume of soil water (Slavich and Petterson 1993). The electrical conductivity of a saturated paste (EC_e) is a measure of salt concentration and is a good approximation of actually soil salinity. Although EC_e is difficult to measure directly, a study by Slavich & Petterson (1993) provided multiplier factors (f) to estimate EC_e from $EC_{1:5}$ using soil field texture grades (Northcote 1979).

Statistical analyses

Vegetation data were analysed for community patterns in the PRIMER package using Bray-Curtis similarity measure for all analyses, this being the most appropriate measure for species data (Clarke and Warwick 1994). The data were standardised but were not transformed as there were no hypothetical reasons for increasing the importance of 'rare' species in the samples. The vegetation community analysis was undertaken on the annual average (arithmetical mean) abundance (frequency) for each species at each site. This procedure was adopted to reduce the size of the dataset and to average the influence of seasonal changes in species abundance. Hierarchical agglomerative clustering (using group averaging) of the similarity matrix in the PRIMER package was used to identify vegetation communities from the dataset and, more specifically, to allocate each of the sample sites to a vegetation community.

Water depth, surface water salinity and soil salinity were compared with vegetation communities, using the sample sites utilised for the vegetation cluster analysis, to define relationships between vegetation and water depth and salinity. Average water depth, surface water salinity and soil salinity (arithmetic means) were calculated for the vegetation communities using all of the vegetation sample sites grouped into each respective community by the cluster analysis. The BIO-ENV procedure in the PRIMER package was used to examine the strength of correlations between the vegetation dataset, as a whole, and water depth, surface water salinity and soil salinity (Bray-Curtis similarity for vegetation; Spearman rank correlation option). The significance of correlations between vegetation communities and water depth, surface water salinity and soil salinity were tested using permutation tests based on the sum of absolute differences of mean water depths, mean surface water salinity and mean soil salinity compared with the grand mean using 1000 permutations in the RESAMPLING STATS package (Blank *et al.* 2001). Relationships between the communities based on the environmental parameters were tested using pair-wise permutation tests based on absolute differences between means, of the water depths, surface water salinity and soil salinity for each community were undertaken using the RESAMPLING STATS package, and applying Bonferroni's adjustment which modifies the significance level (α) to reduce the risk of a type I error resulting from multiple pair-wise comparisons. The adopted significance levels for pair-wise tests were α'=0.00139 for water depth and soil salinity, and α'=0.00333 for surface water salinity.

Results

Vegetation mapping

Eight broad vegetation map units were defined subjectively to describe the vegetation of Hexham Swamp (Table 1). While conceptually finer-scale units could have been defined for the existing vegetation due to the availability of colour aerial photography and the opportunity for detailed ground-truthing, this was not possible for the pre-floodgate vegetation, and the need to prepare comparable maps determined the use of the broader vegetation units.

Vegetation – Environmental Relationships

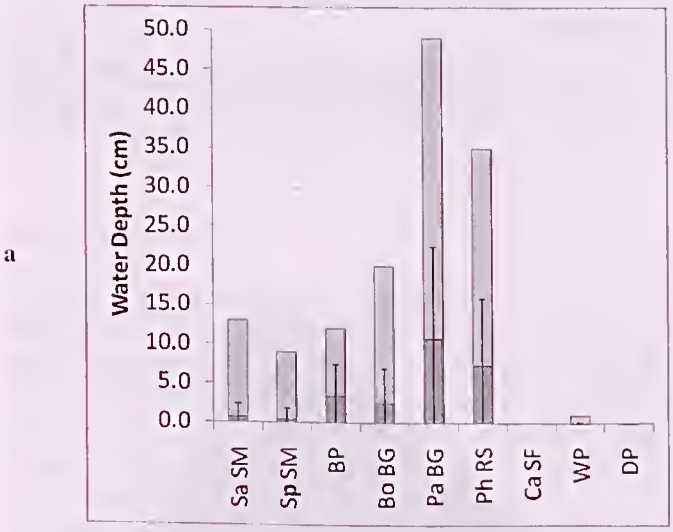
Nine vegetation communities were identified with the assistance of the cluster analysis as representing the vegetation sample sites: *Sarcocornia* saltmarsh, *Sporobolus* saltmarsh, brackish pond, *Bolboschoenus* brackish grassland, *Paspalum* brackish grassland, *Phragmites* reedswamp, *Casuarina* swamp forest, wet pasture and dry pasture, and correspond to the vegetation units defined for vegetation mapping. The division of saltmarsh and brackish grassland each into two communities reflects the finer detail data available for field sampling compared with the broader view applying for

Table 1. Description of vegetation map units showing changes between pre-floodgate (1971) and present (2005).
The approximately 150ha of wetland vegetation missing from the 'existing' mapping has been lost to filling and establishment of non-wetland pasture in previous saltmarsh areas.

Map Unit Name	Description	Area (ha) Pre-floodgate	Existing	Change
Mangroves	Mangrove forest and shrubland dominated by *Avicennia marina*. var. *australasica*	180	11	-94%
Saltmarsh	Saltmarsh dominated by *Sarcocornia quinqueflora*, *Sporobolus virginicus*. and *Juncus kraussii* In the case of the existing vegetation, this map unit is now only represented by relic areas of salt flat dominated by *Sarcocornia quinqueflora* with some *Sporobolus virginicus*.	681	58	-92%
Saline / brackish pond	Open water ponds with inferred extensive growth of *Ruppia* spp. and algae such as *Enteromorpha* spp. Virtually absent from the existing vegetation, being represented now by a number of small brackish ponds in the northeast. *Zannichellia palustris* is a seasonal dominant in these brackish ponds.	59	1	-98%
Brackish swamp	Shallow swamps with a mosaic of dense and sparse growth of *Schoenoplectus littoralis*, Typha orientalis and *Bolboschoenus caldwellii*.	564	39	-93%
Brackish grassland	Areas of low grassland, mostly occurring as part of the existing vegetation in place of original saltmarsh. The main dominant is *Paspalum vaginatum*, occurring in some places with the remnant saltmarsh species *Sporobolus virginicus* and *Juncus kraussii*. *Bolboschoenus caldwellii* occurs as a co-dominant in some areas, evidently in response to reduced grazing by cattle. The introduced Juncus acutus is becoming more common.	-	220	-
Phragmites reedswamp	Reedswamp dominated by *Phragmites australis*. Mostly tall (up to and greater than 2m) and dense. Some areas of less dense reeds growing among brackish grassland are indistinguishable from brackish grassland on aerial photography and would be mapped as the latter.	170	1005	+530%
Casuarina swamp forest	Closed forest and patches of *Casuarina glauca*. Scattered *Casuarina glauca* also occur in other map units.	20	62	+195%
Fresh swamps	A mix of vegetation types occurring on the freshwater margins of Hexham Swamp. Common species include *Eleocharis equisetina*, *Triglochin microtuberosum*, *olboschoenus caldwellii*, *Paspalum vaginatum*, *Ludwigia peploides* and *Persicaria* spp. The vegetation tends to be transilient (changing forms in response to changing water levels) and occurs as mosaics. This map unit also includes small patches of swamp forest dominated by *Melaleuca* spp.	147	271	+84%
TOTALS		**1821**	**1667**	**-8%**

aerial photograph interpretation. The real value of the cluster analysis to this study is not the identification of groups *per se* but the allocation of sample sites to groups.

The BIO-ENV analysis found correlations between water salinity and vegetation (r=0.213), and between soil salinity and vegetation (r=0.227). The correlation between water depth and vegetation was higher (r=0.374). All correlations are statistically significant (p=0.006 for water depth, p=0.003 for surface water salinity, p<0.001 for soil salinity). Both surface water salinity and soil salinity are negatively correlated with water depth, making any combinations of parameters uninformative.



The pair-wise comparisons of water depth revealed significant groupings of the two saltmarsh communities, brackish pond with Bolboschoenus brackish grassland, Paspalum brackish grassland with Phragmites reedswamp, and Casuarina swamp forest with wet and dry pasture. They support the observations that saltmarsh persists on and is restricted to generally drier sites, and that *Paspalum vaginatum* and/or *Phragmites australis* have colonised wetter areas (Figure 2a). The pair-wise comparisons of surface water salinity revealed only two significant groupings, one comprising the two saltmarsh communities this time combined with brackish pond, and the other being Paspalum brackish grassland and Phragmites reedswamp. These groupings reflect the persistence of the original halophytic communities in areas with higher salinity, and its displacement by Paspalum brackish grassland and Phragmites reedswamp in areas with lower salinity (Figure 2b). The data for mean soil salinity yielded few clear-cut associations due to the large variability in soil salinity results within vegetation communities (Figure 2c). Both the pair-wise comparisons and the BIO-ENV analyses suggest that water depth is a better predictor of existing vegetation than either surface water salinity or soil salinity.

Pre 1971 vegetation (pre-floodgates)

The pre-floodgate vegetation is indicative of a large estuarine wetland (Figure 3). Extensive areas of mangroves and saltmarsh occur around Ironbark Creek and its tributaries; small areas of saltmarsh occur in the vicinity of the other historically tidal creeks. On the landward side of these

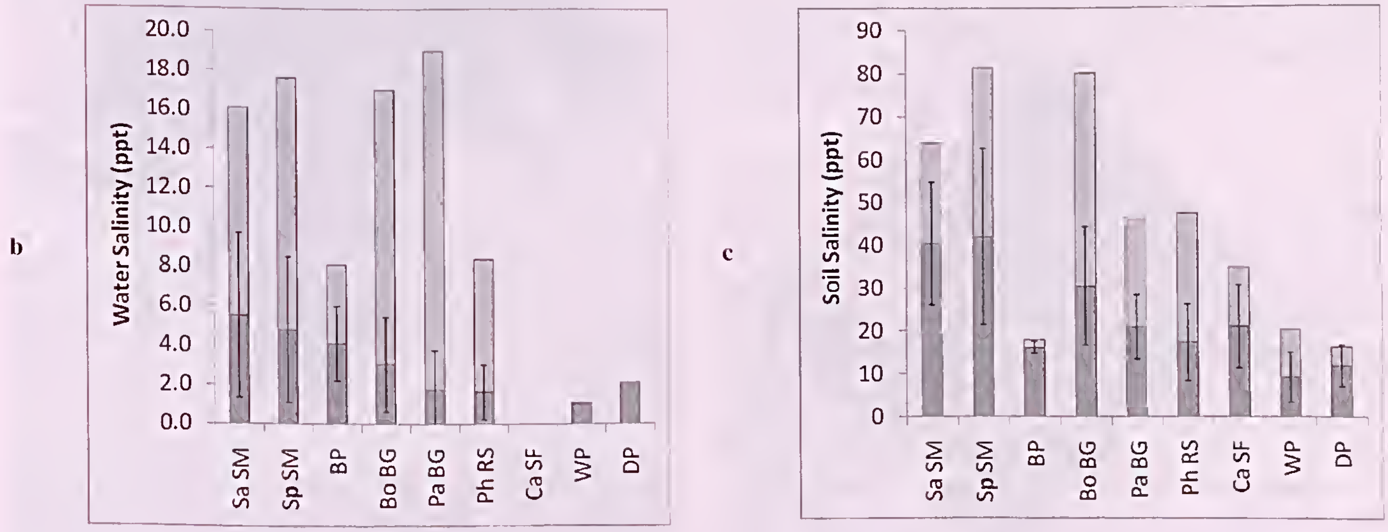


Fig. 2. Relationship between vegetation communities and (a) water depth in centimetres, (b) surface water salinity in parts per thousand and (c) soil salinity in parts per thousand (ECe = saturated paste electrical conductivity, converted to parts per thousand of total dissolved solids). The dark portions of the columns represent mean values, the total column heights represent the maximum values recorded and the error bars represent standard deviation. Sa SM = Sarcocornia saltmarsh, Sp SM = Sporobolus saltmarsh, BP = brackish pond, BoBG = Bolboschoenus brackish grassland, Pa BG = Paspalum brackish grassland, Ph RS = Phragmites reedswamp, Ca SF = Casuarina swamp forest, WP = wet pasture, DP = dry pasture.

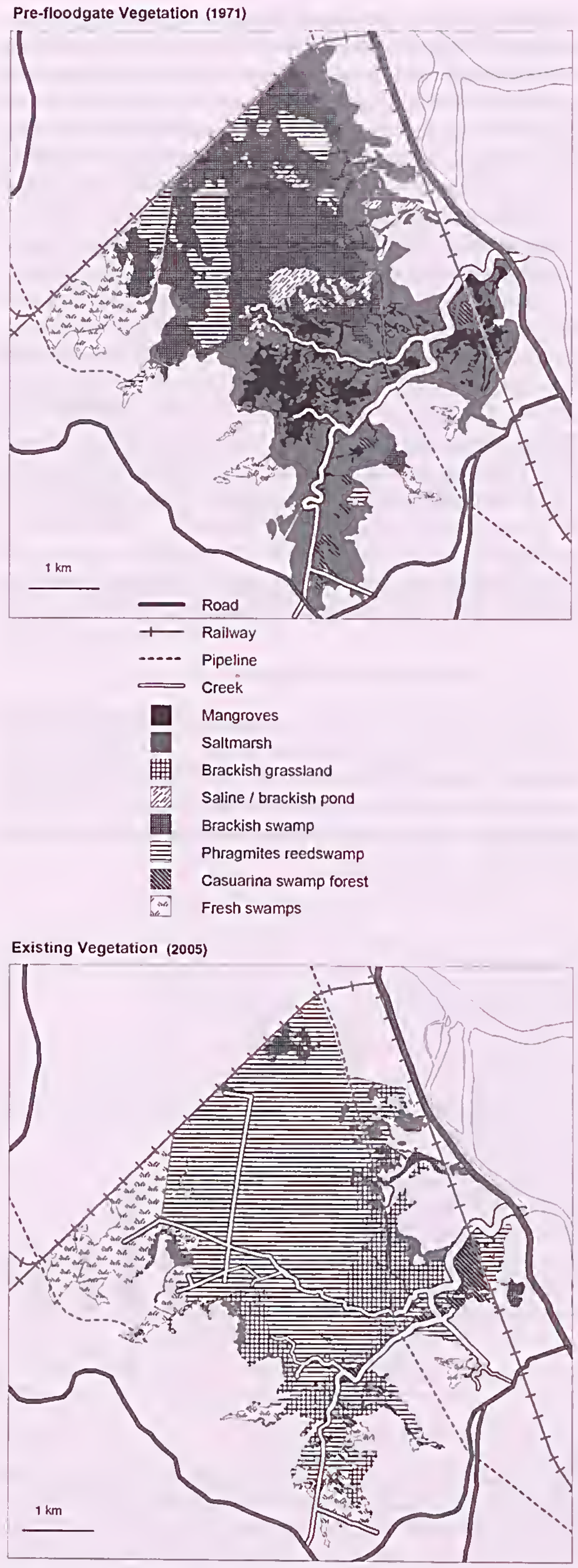


Fig. 3. Pre-floodgate vegetation (top) and existing vegetation (bottom) of Hexham Swamp (1:73 000 approx. scale).

intertidal communities is an extensive area of brackish communities dominated by *Schoenoplectus subulatus, Typha orientalis* and *Phragmites australis.* The digital elevation model (Figure 4) shows a good qualitative correlation with the mapped vegetation (Figure 3). Although Hexham Swamp is generally flat-bottomed, there is a distinct basin in the northern and north-western parts of the swamp where water ponds at a depth of up to approximately 0.5m to 1m. These areas generally corresponded with the brackish marsh community, with *Phragmites* reedswamp occurring on adjacent slightly higher land. Of note in the north-western corner of the swamp are patches of saltmarsh along the edges of the brackish swamp, most of which were still present in 2005, albeit in a degraded condition.

Vegetation changes 1971–2005 (post-floodgate construction)

By 2005, 34 years since the construction of the floodgates, there has been a substantial reduction in area of mangroves

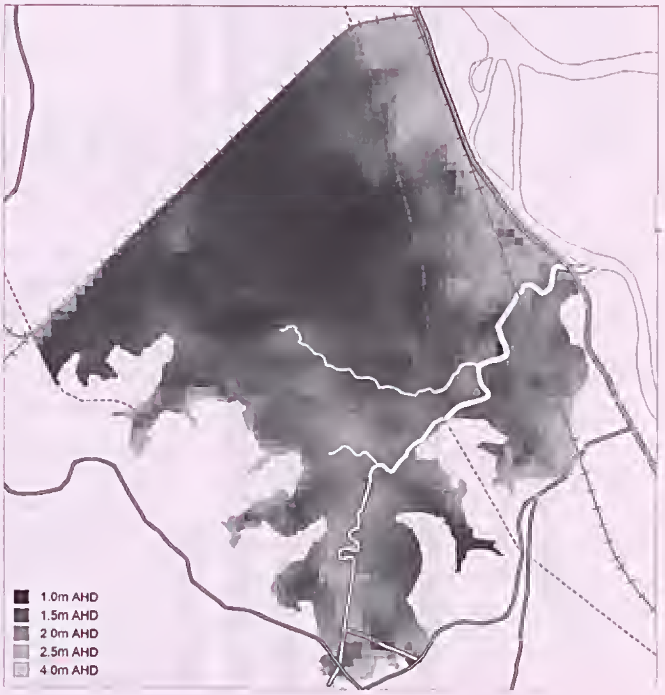


Fig. 4. Digital elevation model (DEM) of Hexham Swamp based on 1968 spot height data. Elevations are in metres AHD (Australian Height Datum). The DEM shows a relatively low area in the central and northern part of the swamp where tidal inflows mixed with freshwater catchment inflows to form a seasonally to semi-permanently inundated basin which supported a brackish swamp of *Schoenoplectus subulatus, Typha* spp., *Bolboschoenus caldwellii* and *Phragmites australis.* Mangrove and saltmarsh occurred on relatively higher ground to the east in the vicinity of the main creeks and to the north where the saline tidal inundation was no diluted by ponded catchment runoff.

which have decreased by 94%, saltmarsh has decreased by 92% and brackish swamp decreased by 98%. *Phragmites* reedswamp has expanded its area by 530% at the expense of all other vegetation types excluding the fresh swamp at the western end of the swamp. *Casuarina* swamp forest expanded by 195% but with limited spatial extent (Table 1, Figure 3).

The loss of halophytic vegetation after restriction or exclusion of tides has been previously documented for the Hunter estuary, including previous studies of Hexham Swamp (Conroy and Lake 1992, King 1999, MacDonald 2001, McGregor 1980, Morrison 2000, Pressey and Middleton 1982, Williams *et al.* 2000, Winning 1996), and elsewhere in New South Wales, such as Yarrahapinni Broadwater (SWC Consultancy 1999) and Tuckean Swamp (NSW National Parks & Wildlife Service 2002). The expansion of *Phragmites australis* into estuarine wetlands subject to tidal restriction is also well documented (MacDonald 2001, McGregor 1980, Pressey and Middleton 1982). Studies in the USA and Europe, where *Phragmites australis* also occurs, have recorded similar trends (Bart and Hartman 2000).

Loss of mangroves

Much of the loss of mangroves in Hexham Swamp (94% since 1971) has been attributed to clearing, although it is likely that a similar loss would have eventually resulted from drainage changes from the floodgates regardless of clearing. It is evident from 1975 aerial photography that a large area of mangroves (approximately 40 ha) had been recently cleared (presumably facilitated by improved access on the drier ground that resulted from the floodgates on Ironbark Creek). McGregor (1980) inspected this area in 1980 and reported that only 137 ha of mangroves remained, and symptoms of stress (dieback) were evident throughout the remnant areas. By 1987 (as interpreted from aerial photos) the total mangrove area has been reduced to 52 ha, 40 ha of which were areas of sparse and low-vigour trees. Some of the lost area is due to filling, primarily as part of Newcastle City Council's 'Astra Street Dump', and it is likely that virtually all of the remainder was the result of clearing as suggested by the total loss of mangroves on privately owned land compared with the continued presence in 1987 of mangrove areas on Crown land, albeit with substantial dieback.

McGregor (1980) undertook investigations into the dieback of mangroves in Hexham Swamp less than 10 years after the construction of the floodgates on Ironbark Creek. Looking at the xylem tension in *Avicennia marina* plants both upstream and downstream of the floodgates, he found that daytime xylem potential in plants upstream of the floodgates was substantially lower during a drought period compared with xylem pressure in a wet period, and compared with plants downstream of the floodgates. In 1990 a study of mangrove dieback in Hexham Swamp (Ericsson 1990) found no significant differences in soil salinity between sites with different degrees of dieback, but did find a slightly higher acidity in surface soil (pH 3.4–4.0) at more degraded sites than at less degraded sites (pH 4.1–4.5), and soils were generally more acidic in Hexham Swamp compared with external controls sites (pH 6–7). Although not demonstrated by Ericsson (1990), the increased acidity is likely to be a result of oxidation of reduced compounds in the drying soil. These two studies suggest that mangrove dieback in Hexham Swamp is, at least in part, a result of drying of the soil, especially during drought periods.

While drying is the most obvious hydrological impact likely to result from restricting the tidal flow into an estuarine wetland, it is also possible that there has been localised ponding of water, increasing over time since the construction of floodgates. The tidal channels that previously served to drain water as the tide dropped now support dense growth of reeds and other plants that would slow drainage and trap sediment. It is possible that increased duration or height of inundation in some areas could have adversely affected mangroves. Even partial smothering of pneumatophores by sediments or water can result in dieback of mangroves (Duke *et al.* 2003, Jimenez and Lugo 1985). Intolerance of flooding by *Avicennia marina* was observed in 'Five Islands' wetlands on Lake Macquarie (NSW) where roadworks in early 2005 temporarily impounded a small estuarine wetland, and dieback was evident within 2 months of heavy rainfall which raised the level of water in the wetland an estimated 20cm above the previous high tide level (Winning 2007).

In summary, mangrove loss in Hexham Swamp subsequent to construction of floodgates on Ironbark Creek was due mainly to clearing, with remaining mangroves succumbing to dieback. The cause of the dieback is likely to be a combination of processes, initially a result of the drying of soil, especially during drought periods, but as drainage channels silted up and became clogged by reeds, ponding of water during wetter periods probably led to 'drowning' of trees by submerging of pneumatophores.

Loss of saltmarsh and brackish swamp

Though the vegetation mapping (Figure 3) showed that *Phragmites australis* has colonised areas that previously supported saltmarsh and brackish swamp, *Phragmites australis* was rarely observed to directly colonise saltmarsh areas during the course of this study, suggesting that an intermediate successional step was involved. Areas of previous saltmarsh that had been observed to undergo successional change during this study were replaced by brackish grassland, dominated by *Bolboschoenus caldwellii* and/or *Paspalum vaginatum*. Some of these areas were observed subsequently to be invaded by *Phragmites australis*, evidently by seed (i.e. well removed from other nearby occurrences of *Phragmites australis*). It is assumed that soil salinity in the previous saltmarsh areas inhibits colonisation by *Phragmites australis* and, probably *Bolboschoenus caldwellii* and *Paspalum vaginatum*. It is hypothesised that both *Bolboschoenus caldwellii* and *Paspalum vaginatum* are initially faster at colonising these areas once soil and water conditions are favourable, but that *Phragmites australis* is competitively dominant over time.

Increased waterlogging, following the blocking of drainage lines by *Phragmites australis* and other plants, is also likely to have contributed to the decline of saltmarsh, allowing invasion by other species (increased wetness could also increase the rate of leaching of salt from the soil). Saltmarsh plants are also sensitive to flooding levels and degree of waterlogging (Clarke and Hannon 1969, 1970), (Siebentritt *et al.* 2004, Turner and Streever 1999). The persistence of some saltmarsh areas in Hexham Swamp reflected persistently high salinity levels, and persistent relative dryness. Saltmarsh areas dominated by *Sarcocornia quinqueflora* were not significantly different to saltmarsh areas dominated by *Sporobolus virginicus* with respect to either wetness or salinity.

Ongoing changes

Data collected for this study show that the vegetation in Hexham Swamp has not yet stabilised, and is still in the process of adjusting to the changing conditions resulting from the construction of the floodgates (and related drainage). In addition to the documented ongoing replacement of saltmarsh by brackish grassland, and the replacement of brackish grassland by *Phragmites* reedswamp, there are increasing numbers of *Casuarina glauca* saplings within areas of the reedswamp. If the floodgates remain and are operated as they are at present, succession is likely to continue as soil salt levels are reduced further (due to leaching) and sedimentation continues, eventually leading to drier communities possibly with more extensive *Casuarina glauca* forest.

Discussion

Hexham Swamp Rehabilitation Project

Within a year of construction of the floodgates on Ironbark Creek in 1971, concerns were raised about their ecological impacts, specifically with respect to fisheries (Evans 1983); within 12 years the possible opening of the floodgates was being raised as an issue for the overall ecology of Hexham Swamp (Keane 1983). By the mid 1990s the Hunter Catchment Management Trust (now Hunter – Central Rivers Catchment Management Authority) had initiated a project to acquire privately owned lands likely to be affected by tidal inundation after the opening of the floodgates, and an environmental impact assessment process. The Hexham Swamp Rehabilitation Project involves the staged opening of floodgates and monitoring of ecological and hydrological changes (Haines et al. 2004). The opening of the floodgates began with the opening of one of the Ironbark Creek floodgates in December 2008 and will continue over the next 4–5 years with the staged opening of the remaining seven. Opening of the floodgates will eventually flood large parts of Hexham Swamp with saline to brackish tidal water. Tidal flows will erode built up sediments, which will gradually lead to more open drainage channels and greater tidal intrusion into the swamp (Haines et al. 2004). Due to hydrological changes both within Hexham Swamp and in other parts of the Hunter River estuary since construction of the floodgates, it is not possible to predict the extent of tidal inundation and, therefore, the likely vegetation changes (Winning 2006). Although a return to pre-floodgate conditions and vegetation is unlikely, a substantial reduction in the area of *Phragmites australis* and a substantial increase in area of tidal communities are likely to occur. As the rehabilitation project proceeds, the hydrological models will be refined potentially enabling better prediction of changes in the later stages of the project (Haines *et al.* 2004). The data from the project should also allow predictions of impacts within Hexham Swamp associated with future sea level rise, and possibly inform climate change impact assessment for other wetlands.

Virtually all of the existing vegetation within Hexham Swamp is of types listed as endangered under the NSW *Threatened Species Conservation Act 1995*. The *Phragmites australis* dominated vegetation and other freshwater communities fall within the endangered ecological community *Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions* (FWCF). Areas dominated by *Casuarina glauca* fall within *Swamp oak floodplain forest of the NSW North Coast, Sydney Basin and South East Corner bioregions* (SOFF). Remnant saltmarsh areas fall within *Coastal saltmarsh in the NSW North Coast, Sydney Basin and South East Corner bioregions* (CS). The rehabilitation of the swamp will result in a reduction in area of each of both FWCF and SOFF, although there would be an expansion of CS. There would also be an expansion of mangrove forest, which is not listed as an endangered ecological community. In the planning and approval of the Hexham Swamp Rehabilitation Project judgements have been made that the loss of a large area of *Phragmites australis* dominated FWCF, in particular, is an acceptable trade-off for the gain of a large area of estuarine vegetation, including CS, and associated habitat values.

As with most rehabilitation projects, the Hexham project is based, in part, on the premise that the previous condition was of greater ecological value than the current condition. In this case, the previous fisheries value of Hexham Swamp was a major driver for the rehabilitation initiative, although the objectives of the project are broader, these being *inter alia*, to:

- increase habitat diversity by restoring estuarine habitats within the project area;
- improve habitat for estuarine fauna and aquatic fauna;
- encourage research into the optimal management of the swamp (Haines *et al.* 2004).

The Hexham Swamp Rehabilitation Project presents an excellent opportunity to monitor the changes that occur subsequent to reintroduction of tidal inundation, and to research options for managing estuarine wetland rehabilitation. Data gathered for the study described herein will be part of a 'before' dataset for a comprehensive BACI design assessment of vegetation changes subsequent to the staged opening of the Ironbark Creek floodgates which commenced in December 2008 with the managed opening of one floodgate. The schedule for opening future floodgates will be, in part, influenced by the results of the monitoring of the effects of the opening of the first floodgate.

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Monitoring vegetation change over 30 years: lessons from an urban bushland reserve in Sydney

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Abstract: For the successful long-term management of biodiversity in conservation reserves, science and management need to work together. In 2008 we resampled two transects in a small urban reserve in northern Sydney under long-term conservation management. The transects were established in 1976 and recorded again in 1987 and 1998 (by other workers). We looked at plant species changes by growthforms, family (Fabaceae) and conservation-significance. Over the 30-year period the structure of the understorey has changed markedly, and despite ongoing weeding programs, the frequency of species identified as significant for conservation has continued to decrease. Despite periodic recommendations for ecological burning since 1987, supported by the monitoring data, this has not been attempted. We discuss the lessons for ecology, monitoring and management evident in this long-term monitoring study.

Key words: vegetation monitoring, adaptive management, understorey change, fire impacts

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Introduction

For the long-term management of biodiversity in conservation reserves, both science and management are needed if successful conservation outcomes are to be achieved. An adaptive management program will allow the results and recommendations coming out of scientific monitoring to be acted upon. This study in a small urban bushland reserve over a 30 year period looks at these issues in practice.

The Ludovic Blackwood Memorial Sanctuary (Blackwood) at Beecroft in the northern suburbs of Sydney conserves a 1.2 ha remnant of Blue Gum High Forest (BGHF), which is listed as an Endangered Ecological Community under both the NSW Threatened Species Conservation Act 1995 and the Australian Government Environment Protection and Biodiversity Act. BGHF occurs in high rainfall areas on clay soils derived from the Wianamatta Shale.

The National Trust of Australia (NSW) – who owns and manages Blackwood – engaged the Bradley sisters in the mid 1970s to advise on managing the vegetation of the site, and the Bradleys and the National Trust conducted early trials in handweeding and minimal disturbance approaches to bush regeneration that have since been adapted and widely applied throughout Australia (Bradley 2002).

Previous reports

Blackwood was also the site of a relatively early example of scientific documentation in urban bushland. In January 1977, in response to increased awareness of shrubby urban bushland weeds (particularly *Ligustrum lucidum*, Large-leaved Privet), the National Trust commissioned a report *The Ludovic Blackwood Memorial Sanctuary – description and management* (Buchanan 1977). As well as making general observations on the tall *Eucalyptus* canopy and indicating that some of the groundlayer shale species were regionally rare at that time, Buchanan set up and recorded three 20m x 1m permanently marked transects to measure groundcover vegetation. At the time Blackwood had mown areas, areas of dense *Pittosporum undulatum* (Sweet Pittosporum) and weedy areas. The mowing stopped in the late 1970s. Buchanan's report not only outlined approaches to weed control but also drew attention to the abundant growth of the native shrub *Pittosporum* which formed a dense, 80–100% cover over much of the site, and discussed its role in native plant suppression.

Buchanan had two management objectives, removal of exotic weeds and encouragement of native plant regeneration. She was confident that unless the exotic *Ligustrum lucidum* was weeded out, it would eventually form a dense shrublayer

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replacing the *Pittosporum*. She also argued that the dense growth of *Pittosporum* was the result of many fire-free years, and that in the event of a fire these would be killed, while other less common shrubs would survive and flourish. She envisaged that, in the absence of fire, the gradually senescing *Pittosporum* might be replaced by either young regrowing *Pittosporum* or other light requiring species from the mowed borders (she did not know which).

In 1987, in a second report, Buchanan (1987) reported that the weeding program was becoming effective; the *Pittosporum* had been reduced and the native plant species richness had increased. However the understorey species characteristic of the shale soils had declined in frequency, probably due to the absence of substantial disturbance necessary for seedling recruitment, while the herbs, grasses and creepers typical of sheltered gully habitats had increased. To create the disturbance necessary for the recruitment of the shale species, Buchanan recommended a program of burning at 10 year intervals. Apart from some very limited pile burns (about 1 m^2) no burning was carried out.

Pittosporum undulatum is a native species in moist vegetation on medium to high nutrient soils in coastal NSW (such as Blue Gum High Forest at Blackwood) (Howell 2003) though it has spread to become a bushland weed in parts of southern Australia, beyond its natural range (Gleadow & Ashton 1981, Gleadow 1982, Blood 2001). The *Pittosporum* plants (native to Blackwood and noted there in the 1960s) probably recruited in the 1950s, a high rainfall period, and probably following cessation of periodic horse or cattle grazing (which would have been a common use of grassy forest blocks in the first half of the 20th century. The irregular mowing of some areas in the 1970s would have maintained a similar low groundcover impact as grazing, allowing forb and grass species to survive in, and adjacent to mowed areas. Clearing of *Pittosporum* between 1977 and 1987 provided the canopy removal impacts of fire but did not provide the bare ground and heat treatments associated with fire. With the physical removal of the shrub canopy in the 1980s, the vine component took over and spread to become the main understorey canopy layer.

In 1998 Stanton remeasured the Buchanan transects. By1998 the abundance, dominance, and smothering habit of the climbers were having a detrimental effect on regeneration of the vegetation, though the removal of *Pittosporum* had been effective in increasing species richness of previously densely shaded area (Stanton 1998). There was no regeneration of *Pittosporum* in areas from which it had been removed.

Stanton (1998) made recommendations including

- the climbers *Pandorea pandorana*, *Clematis aristata*, *Cayratia clematidea* and *Eustrephus latifolius* should be removed from regenerating trees, shrubs, herbs and grasses
- Fire should be used as a management tool
- Fire intensity should be as high as possible
- Only small sections of the reserve should be burnt at one time followed by a one year study of burn sites
- Weed removal should continue throughout the reserve

A decade has passed since Stanton's recommendations, and though weed control continues in Blackwood, there has been no use of fire. Though the initial methodology only enabled basic statistical analysis, the careful recording of marked plots at 10 year intervals by Buchanan and Stanton provided the impetus to re-record them and assess the vegetation changes over a 30 year period.

The 2008 monitoring

We visited Blackwood in February 2008 to re-record Buchanan's Transects 1 and 3. Neither the Bush Management teams nor National Trust management knew of the location of the original transect markers, so we relocated the sites using measuring tape and compass bearings as accurately as we could from Buchanan's original map of the area. The 2008 plots were marked with steel posts. We recorded species presence in each of the 20 1m x1m plots along each transect as Buchanan did, using a 1–4 scale for abundance within each 1m x 1m plot. Although not precisely located on the original lines, the visual evenness of the vegetation in the immediate site indicated that our recordings are likely to provide a valid comparison.

One-off recordings at 10 year intervals are likely to be affected by seasonal conditions. Buchanan's recording was done in November 1976/ January 1977, and January 1987. Stanton recorded in May 1998, following rain after a hot, dry summer. To be close to Buchanan's timing we recorded in February 2008, during an unusually wet summer. At nearby Parramatta 627 mm rainfall was recorded in the previous six months compared with the long term mean of 393 mm (Bureau of Meteorology).

Data on species richness and individual species frequencies were compared with Buchanan's and Stanton's reports; both of which include appendices of raw data.

Table 1. Native plant species richness (species/sq m +/- se) for two transects at Blackwood Sanctuary Beecroft, 1976–2008.

Transect	1976/77	1987	1998	2008
1	5.1 +/- 0.74	9.5 +/- 1.15	10.2 +/- 0.61	7.5 +/- 0.46
3	9.3 +/- 0.53	10.8 +/- 0.58	10.5 +/- 0.91	10.8 +/- 0.43

Results

Native Species richness per quadrat

Buchanan (1987) reported that between 1977 and 1987 native plant species richness (species/m^2) improved 'dramatically' at Transect 1 and 'increased' at Transect 3 due to an increase in sheltered gully species rather than significant shale species. Levels remained similar in 1998, but in 2008 there was a decrease at Transect 1, though little change at Transect 3. Species richness in 2008 was higher than in 1976 (Table 1). Such results suggest there is little ongoing change in the vegetation. However species richness measures are of limited use in looking at long-term changes, as new species appearances may be counterbalanced by existing ones disappearing; leaving measures with no nett change, though the vegetation dynamics may have changed considerably.

Growthform group changes over time

There have been 56 native species and more than 12 exotics recorded from the two transects over the four recording dates, about 40% of the 139 native species recorded for the whole reserve since 1974. We grouped species by growth-form into shrubs, vines, forbs and grasses/graminoids as used by Buchanan and Stanton. Over the 30 year period the major trend has been an increase in frequency of vine species, with the mean frequency for the 7 species increasing from 10% (2/20) to nearly 60% (12/20) (Figure 1). Fern frequency also rose, particularly in the last 10 years. The mean frequency of grasses, graminoids and groundcover forbs increased in the first decade, presumably in response to the light provided by the removal of the *Pittosporum*, but decreased in the last decade. In 2008 grasses and graminoids were still higher

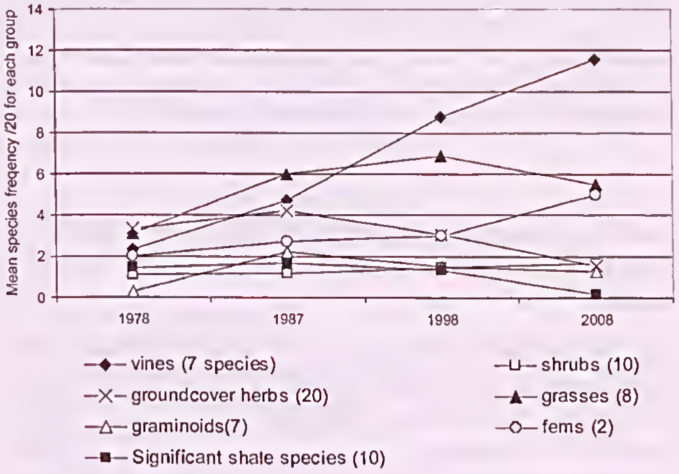

Fig. 1. Mean species frequency for six understorey vegetation growth form groups and the group of conservation-significant shale species at Blackwood over a 30 year period (1976–2008) showing relative increase in importance of vines.

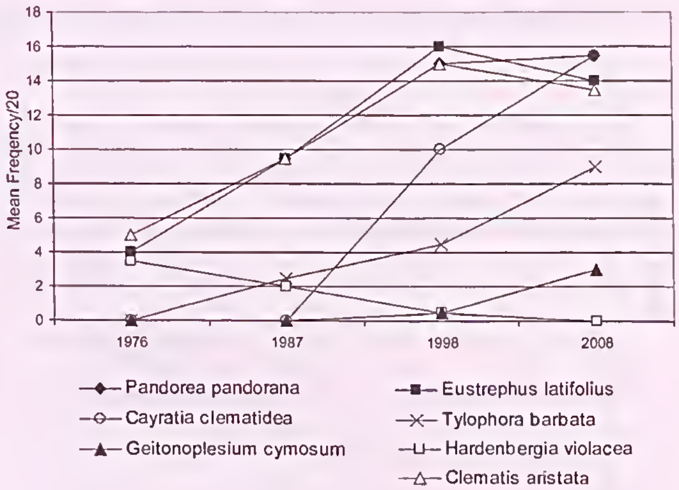

Fig. 2. Mean species frequency for individual vine species at Blackwood (1976–2008) showing increase in most species except *Hardenbergia*.

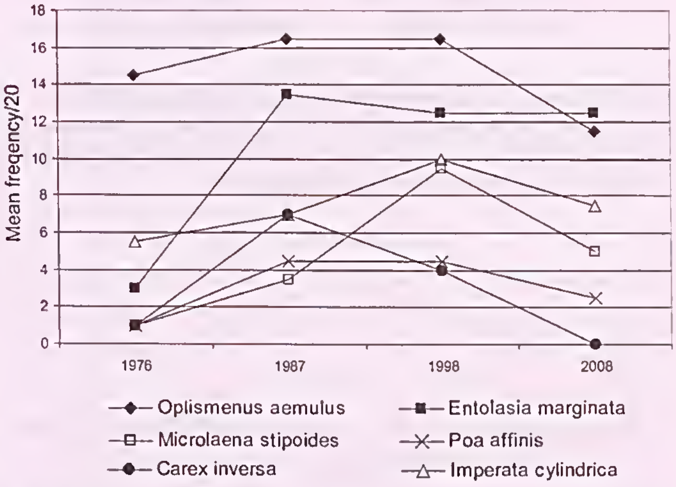

Fig. 3. Mean species frequency for individual monocot species (mostly grasses) at Blackwood (1976–2008) showing initial increase and subsequent decrease for most species.

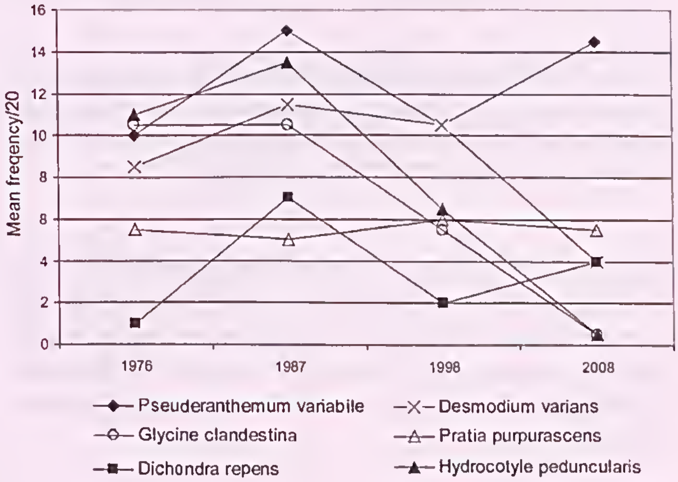

Fig. 4. Mean species frequency for individual groundlayer forb species at Blackwood (1976–2008) showing decrease for some (*Hydrocotyle*, *Glycine*) but relatively stable abundance for others.

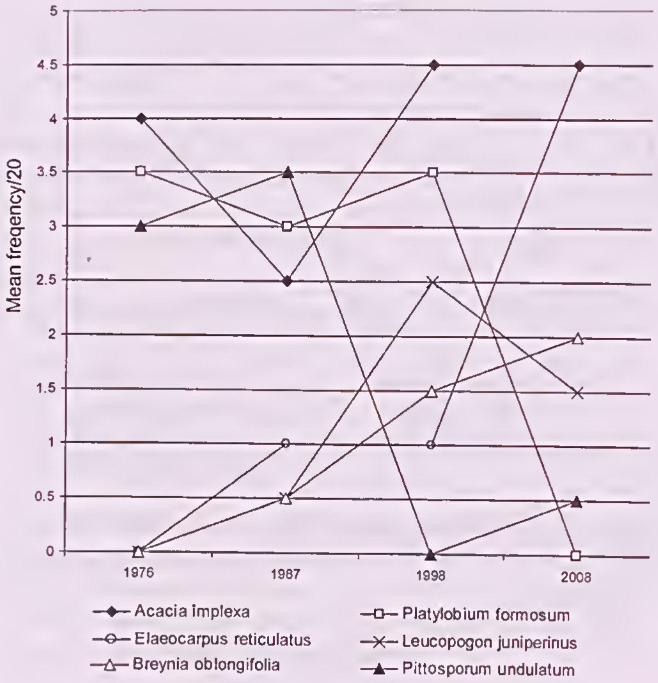

Fig. 5. Mean species frequency for individual shrub species at Blackwood over 30 year period (1976–2008) showing decreases for some species (*Pittosporum* – removed, *Platylobium*) but increases in others (*Elaeocarpus, Breynia Leucopogon*).

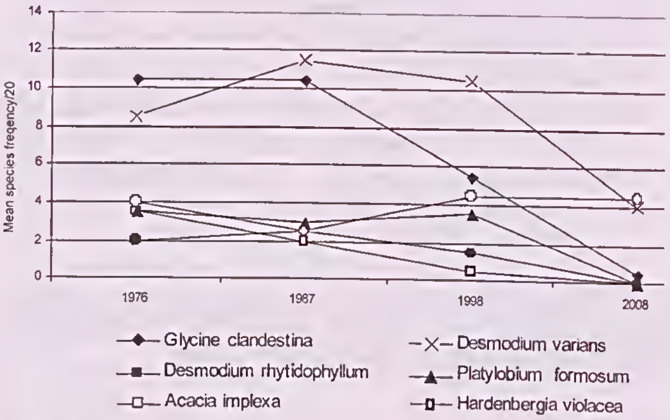

Fig. 6. Mean species frequency for individual Fabaceae species over 30 year period at Blackwood (1976–2008) showing decline of some (*Glycine, Desmodium, Hardenbergia, Platylobium*) but persistence of *Acacia implexa* as *Pittosporum* is cleared in 1980s, followed by decrease as vines form dense canopy.

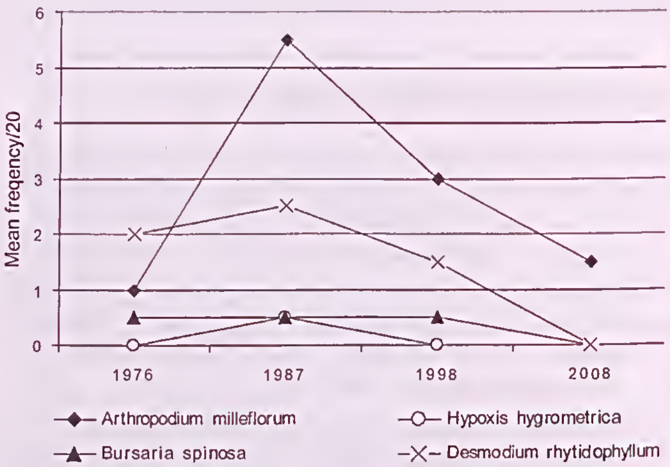

Fig. 7. Mean species frequency for individual long-lived conservation-significant species over 30 year period at Blackwood (1976–2008) showing decrease as vines form dense canopy.

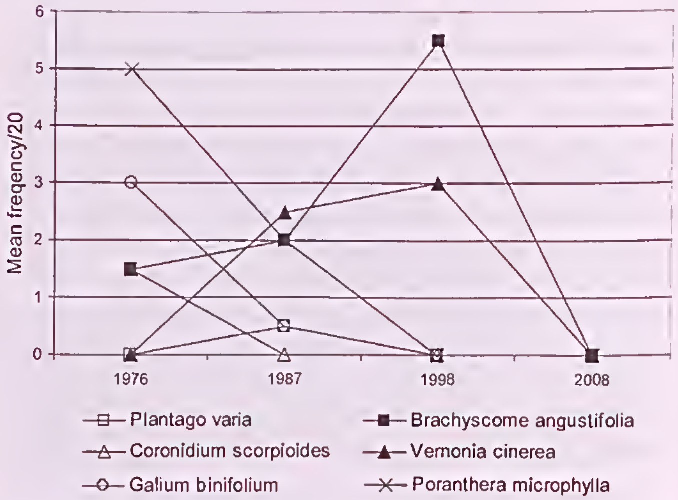

Fig. 8. Mean species frequency for individual short-lived conservation-significant shale species over 30 year period at Blackwood (1976–2008) showing decline of some (*Galium, Helichrysum, Poranthera*), but episodic increase for others (*Brachyscome, Vernonia*) as *Pittosporum* is cleared in 1980s, followed by decrease as vines form dense canopy.

than 1976, but groundcover forbs lower. Shrub frequency remained more or less constant over the 30 year period. The mean frequency of the significant shale species decreased. Overall vine and mesic shrubs have increased in frequency and dominance at the expense of the lower growing herbs and monocots.

Species changes over time

Though changes in growth-form groups give a picture of the coarse changes in vegetation, it is important to understand what is happening to species within each group as management responses will ultimately be aimed at particular species.

Figures 2–5 show changes over the 30 year period for the most frequent species in each of the growthform groups. Except for *Hardenbergia violacea,* all the vine species particularly *Pandorea pandorana, Clematis aristata, Cayratia clematidea* and *Eustrephus latifolius* have been increasing markedly since 1976 (Figure 2).

Of the frequent grass and graminoid species (Figure 3), most increased in frequency between 1977 and 1998 but then dropped, with some, in 2008, still above 1976 frequency.

Table 2. Blackwood monitoring study: native plant species with frequencies (max 20) in the two 20 m transects recorded at 10 year intervals from 1976 to 2008. Buchanan Indicator species noted #

Native species (Family)	Transect 1				Transect 3			
	1976	1987	1998	2008	1977	1987	1998	2008
Climbers/vines								
Cayratia clematidea (Vitaceae)	0	0	17	19	0	0	3	12
Clematis aristata (Ranunculaceae)	3	9	20	14	7	10	10	13
Eustrephus latifolius (Philesiaceae)	3	11	17	10	5	8	15	18
Geitonoplesium cymosum (Philesiaceae)	0	0	0	1	0	0	1	5
Hardenbergia violacea (Fabaceae)	3	4	1	0	4	0	0	0
Pandorea pandorana (Bignoniaceae)	3	9	15	16	5	10	15	15
Tylophora barbata (Apocynaceae)	0	0	0	0	0	5	9	18
Groundcovers grasses, graminoids								
# Arthropodium milleflorum (Anthericaceae)	1	5	3	2	1	6	3	1
Carex inverse Cyperaceae)	2	3	2	0	0	11	6	0
Dianella caerulea (Phormiaceae)	0	0	0	3	0	0	0	4
Dichelachne rara (Poaceae)	0	0	0	0	0	5	3	0
Digitaria ramularis (Poaceae)	0	0	0	0	0	0	0	2
Echinopogon caespitosus (Poaceae)	0	0	1	2	0	1	0	6
Entolasia marginata (Poaceae)	1	10	12	7	5	17	13	18
# Hypoxis hygrometrica (Hypoxidaceae)	0	0	0	0	0	1	0	0
Imperata cylindrica (Poaceae)	4	8	9	8	7	6	11	7
Lomandra filiformis (Lomandraceae)	0	0	0	1	0	0	0	0
Lomandra longifolia (Lomandraceae)	0	0	1	7	0	3	5	0
Lomandra multiflora (Lomandraceae)	0	2	1	0	0	0	0	0
Microlaena stipoides (Poaceae)	1	2	8	1	1	5	11	9
Oplismenus aemulus (Poaceae)	11	20	17	7	18	13	16	16
Poa affinis (Poaceae)	1	6	4	3	1	3	5	2
Groundcovers Forbs/ferns								
Adiantum aethiopicum (Adiantaceae)	0	0	0	0	0	0	0	6
# Brachyscome angustifolia (Asteraceae)	0	0	0	0	3	4	11	0
Brunoniella australis (Acanthaceae)	0	9	8	0	0	4	7	0
Centella asiatica (Apiaceae)	0	0	0	0	0	0	0	2
# Desmodium rhytidophyllum (Fabaceae)	0	0	0	0	4	5	3	0
Desmodium varians (Fabaceae)	13	17	17	2	4	6	4	6
Dichondra repens (Convolvulaceae)	2	7	0	1	0	7	4	7
# Galium binifolium (Rubiaceae)	6	1	0	0	0	0	0	0
Glycine clandestina (Fabaceae)	9	8	6	0	12	13	5	1
Goodenia hederacea (Goodeniaceae)	0	0	0	0	2	1	0	0
# Coronidium scorpioides (Asteraceae)	0	0	0	0	3	0	0	0
Hibbertia serpyllifolia (Dilleniaceae)	0	0	0	0	1	0	0	0
Hydrocotyle peduncularis (Apiaceae)	2	10	5	0	20	17	8	1
Opercularia varia (Rubiaceae)	0	1	0	0	0	1	0	0
Oxalis ? corniculata (Oxalidaceae)	1	1	0	1	9	3	6	2
# Plantago varia (Plantaginaceae)	0	0	0	0	0	1	0	0
Plectranthus parviflorus (Lamiaceae)	2	3	0	0	0	0	0	0
# Poranthera microphylla (Euphorbiaceae)	0	0	0	0	10	4	0	0
Pratia purpurascens (Lobeliaceae)	7	6	7	8	4	4	5	3
Pseuderanthemum variabile(Acanthaceae)	1	14	14	14	19	16	7	15
Pteridium esculentum (Dennstaedtiaceae)	5	6	7	6	3	5	5	8
# Vernonia cinerea (Asteraceae)	0	0	5	0	0	5	1	0
Shrubs								
Acacia implexa (Fabaceae)	7	4	8	2	1	1	1	7
Acmena smithii (Myrtaceae)	0	0	0	0	0	0	0	2
Breynia oblongifolia (Euphorbiaceae)	0	1	2	2	0	0	1	2
# Bursaria spinosa (Pittosporaceae)	0	0	0	0	1	1	1	0
Elaeocarpus reticulatus (Elaeocarpaceae)	0	1	2	4	0	1	0	5
Leucopogon juniperinus (Epacridaceae)	0	0	0	2	0	1	5	1
Notelaea longifolia (Oleaceae)	0	0	1	0	0	0	0	0
Pittosporum undulatum (Pittosporaceae)	4	6	0	1	2	1	0	0
Platylobium formosum (Fabaceae)	0	1	0	0	7	5	7	0
Polyscias sambucifolia (Araliaceae)	0	0	1	5	0	0	0	0
Trees								
Angophora floribunda (Myrtaceae)	0	0	0	0	0	0	0	1
Eucalyptus pilularis (Myrtaceae)	0	0	1	0	0	0	0	2

These include the grasses *Entolasia marginata, Imperata cylindrica, Microlaena stipoides* and *Poa*. Both *Oplismenus aemulus* and the sedge, *Carex inversa* were below the 1976 frequency.

The frequent groundcover forbs have remained generally stable (*Pseuderanthemum variabile, Pratia purpurascens, Dichondra repens*) or decreased (*Desmodium varians, Hydrocotyle peduncularis, Glycine clandestina*) (Figure 4) (Table 2).

Although the shrub species as a group remained constant there was a change in species composition (Figure 5); some species such as *Platylobium formosum* and *Pittosporum* having decreased. More mesic species such as *Elaeocarpus reticulata* and *Breynia oblongifolia* and *Leucopogon juniperinus*, however, increased.

Fabaceae, a hard-seeded family, changes over time

Species in the Fabaceae family have generally done poorly (Figure 6). Despite the general increasing trend for vines, *Hardenbergia violacea* decreased over the 30 year period and was not recorded in 2008. Similarly the forbs *Desmodium rhytidophyllum* and *Glycine clandestina* and the shrub *Platylobium formosum* have decreased. Fabaceae species have hard-coated seeds which require heat for germination and have evidently not had suitable conditions for recruitment, although some species can regrow from rootstocks after disturbance.

Decrease of significant shale species

By 2008 the significant shale indicator species (Figures 7,8) have decreased markedly; only one, *Arthropodium milleflorum*, out of 10 species was recorded in the transects. Over the 30 years, some have been gradually declining (*Coronidium scorpioides, Poranthera microphylla, Galium binifolium, Bursaria spinosa*); others increased in response to the *Pittosporum* clearing and subsequently declined (*Arthropodium milleflorum, Hypoxis hygrometrica, Plantago varia*), while others show a marked pulse in the 1998 recording (*Brachyscome angustifolia, Vernonia cinerea*), possibly related to good rainfall conditions following the hot summer. Some species still occur outside the transects, in previously mowed areas (*Galium binifolium, Bursaria spinosa*), though 6 were not recorded in a general recording of the reserve in May 2003 (Benson & Howell 2003) and may only exist in the soil seedbank, if at all.

Discussion

In 10, 50 or even 100 years this report can be used as the base line so that, if accurate records are kept, it will be known what management procedures have led to changes, if any, in the vegetation of the Sanctuary. (Robin Buchanan 1977)

In 1978, two decades before the formal listing of the Blue Gum High Forest as an Endangered Ecological Community, Buchanan recognised the conservation significance of the remnant of Wianamatta Shale flora at Blackwood. She highlighted the significance of the groundlayer species of heavy or deep soils such as *Vernonia cinerea, Sigesbeckia orientalis, Conidium scorpioides* and *Imperata cylindrica* which were mixed in with tall shrub species typical of sandstone gullies eg *Pittosporum, Acmena smithii, Myrsine variabilis* and *Allocasuarina torulosa*. The shale groundlayer species, highlighted in 1977 as being the most significant for conservation, have virtually disappeared (except perhaps in some of the previously mowed areas around the reserve margins).This is largely a result of management actions which have concentrated on weed removal but have not responded to associated changes in native species taking place, despite repeated calls based on the monitoring program.

Understorey dynamics in a grassy/shrubby open-forest understorey

Larger growing shrubs such as *Pittosporum* (and woody exotics such as *Ligustrum lucidum*) tend to outgrow and shade out smaller understorey species in the absence of disturbance (fire, drought, periodic grazing). Time frames relate to the longevity of the main structural species, the tall shrub *Pittosporum*, individuals of which are fire-sensitive and live about 30–40 years (Benson & McDougall 1999). (The exotic *Ligustrum lucidum* is fire-resistant and lives much longer). Conceivably in BGHF in the pre-European environment, local understorey dominance by *Pittosporum* over 30–40 years (in the absence of fire), and subsequent overgrowth by vines in the subsequent 20 years as the *Pittosporum* died out (at Blackwood of course removed prematurely), could have been a localised inter-fire event (occupying at least 60 years) in some particular moist /sheltered sites. There would be unlikely to be any change to the overstorey *Eucalyptus* species (which probably live 100–200 years) during this time. At the same time, in adjacent BGHF on sites not suitable for dense *Pittosporum* recruitment (either too dry, open, or subject to occasional burning or grazing), the grassy groundcover shale species could have predominated. As such these processes and mixtures of species are *natural*, but required the larger landscape to coexist.

However the problem in the 2008 context is that we have to manage for the long-term survival of all native species, and in particular a group of shale species of open sites, in only a small remnant (1.2 ha) of the original area of BGHF, and deal with the impacts of ecological processes that have previously operated at the landscape scale.

How resilient is the system?

Bushland sites include not only those species that are obvious in the existing above-ground vegetation. Many species have a soil-stored seedbank, supressed rootstock or soil-stored tubers. Some may be able to disperse into suitable habitat from adjacent areas.

Though the shale species were not recorded in the transects in 2008, *Sigesbeckia orientalis* is still present in Blackwood in disturbed sites. Several other species including *Vernonia cinerea* were recorded as abundant in 1998, with rain following a dry El nino year. These are short-lived species that are likely to remain in the soil seedbank; 10 years is not a long period of time for seed to remain. For example species of *Desmodium* and *Arthropodium* have germinated after 14 years in storage, and *Vernonia* after 12 years (Hong et al. 1998), though there is no data for the particular species at Blackwood.

What is needed is to maximise the variation in habitat patchiness within Blackwood so that conditions for a wider range of species are improved. In small reserves a mixture of treatments to enhance habitat variation is necessary if all species are to be conserved.

A program incorporating burning of relatively large areas, some regular mowing of trails and some less frequent coarser slashing of small areas may provide a wider range of microhabitat conditions for recruitment of species that are not currently evident, but may be present as soil-stored seed or rootstock. This needs to be done in concert with ongoing control of exotic weeds.

Lessons for monitoring from the Blackwood study

The simple fixed-transect vegetation monitoring program was efficient time-wise (though requiring expert identification ability) and demonstrated results over a 30 year period

It is necessary to record individual species changes over time. Species richness measures are of limited use for evaluating long-term changes, as new species appearances may be counterbalanced by existing ones disappearing, leaving measures showing no nett change though vegetation dynamics may have changed considerably.

Monitoring results need to be publicly available, as over the long-term different stakeholders are likely to take an interest, and ongoing recording is more likely to be maintained if earlier results are available.

Lessons from management at Blackwood

The conservation aims were clearly defined (conservation-significant species were highlighted), monitoring did provide a measure of the change after each 10 year recording, and subsequent recommendations were increasingly supported by data. Management responded positively to the recommendations for the removal of *Pittosporum* and woody weeds in the 1980s.

However the recommended burns were never carried out. This was probably due to bureaucratic problems, such as lack of access to, or awareness of, the original reports, staff changes and physical difficulties, e.g. weather in arranging for the burns. Resolution for action was weakened by varying opinions on whether burning was really needed, generally without reference to the monitoring data.

Clearing of *Pittosporum* provided the physical effects of fire but did not provide the bare ground cover and heat treatments provided by fire. With the physical removal of the shrub canopy in the 1980s the vine component took over and spread as the main understorey canopy layer.

Recommendations in 2008 are for burning, as in 1987 and 1998, but more urgent, as suppressed plants and soil seedbank gradually deteriorate under the increasingly thick vine canopy.

Periodic monitoring of marked sites and observance of the trends are essential if we are to improve conservation outcomes in bushland reserves. While a single visit to the site would reveal the impacts of *Pittosporum* shading or weed invasion, the gradual rate of vegetation change, at least in terms of the shale species, was not obvious, especially in the absence of the monitoring data.

Conclusions

While we can't necessarily retain all native plant species in a small reserve in the long-term, it is important to understand the significant regional contribution that a small reserve can make and identify the species and components that should be prioritised for long-term management.

Monitoring of fixed plots at Blackwood at 10 year intervals over 30 years clearly documented the changes in the vegetation taking place. Important and repeated recommendations arising from these assessments were only partly implemented. Consequently the group of species identified as of particular conservation significance for this reserve may have been lost or are severely depleted. Whether they can be recovered remains unknown.

For the long-term management of biodiversity in conservation reserves, science and management need to work together if successful conservation outcomes are to be achieved.

Acknowledgements

We would like to acknowledge Robin Buchanan's foresight and attention to detail in setting up the sites in 1976 when general community knowledge and appreciation of plant identification was in its infancy. We thank Lotte von Richter and Elisabeth Dark for help with the recent fieldwork.

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Seed fill, viability and germination of NSW species in the family Rutaceae

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Abstract: The New South Wales Seedbank (at Mount Annan Botanic Garden) stores seeds of both common and threatened species for conservation, research and restoration or revegetation projects. The value of the collections depends on our ability to germinate seeds once they have been retrieved from storage. The collection includes 129 collections representing 93 taxa in the family Rutaceae, but seed viability in Rutaceae is variable, germination cues are poorly-understood and problems are likely to arise in trying to grow plants from seed.

In this study we quantified seed fill and/or viability and germination for 112 species in the Rutaceae family. For many of the species, this is the first time that these seed characteristics have been recorded. We found that seed fill (0–100%) and seed viability (0–97%), were highly variable, with 80% of collections having low viability (<75%). There was also a trend for threatened species to have lower seed fill than common species, while viability and germination were similar. This review reaffirms the need for further study of seed characteristics in Rutaceae.

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Introduction

Plant species in the family Rutaceae make up a significant component of the understorey in many temperate Australian plant communities, particularly in low-nutrient habitats, as well as a high proportion of regionally endemic species (Auld 2001). In New South Wales 26% of 252 native Rutaceae species are threatened (Botanic Gardens Trust 2008).

A representative collection of seeds is an important component of both common and threatened species conservation. Long-term seed storage is a requirement of many threatened species Recovery Plans and a recommended action in many Threatened Species Priorities Action Statements (Department of Environment and Climate Change 2007). Seeds of common species such as Geijera parviflora are also needed for growing from seeds by groups such as Greening Australia (D. Carr, pers.comm.).

However problems are likely to arise in trying to grow Rutaceae family plants from seeds as seed viability is variable and germination cues are poorly understood (Roche et al. 1997, Auld 2001, Floyd 2008). While many ornamental genera including *Boronia*, *Correa* and *Crowea* can be propagated from cuttings this does not allow much genetic variability to be retained. Seed research in Rutaceae has been hampered by low seed numbers and poor viability, making it difficult to collect sufficient seeds to study germination and dormancy. However, with an increase in conservation initiatives such as *ex situ* seed banking, it is imperative that effective methods for successful germination are identified (Smith et al. 2003).

The first step in determining whether seeds can be used to produce healthy plants is to determine whether seeds are filled and viable. Seed fill is a measure of the proportion of outwardly undamaged seeds that have all the tissues essential for germination (that is, an intact endosperm and embryo). **Seed fill** has not often been documented separately to seed viability, as seeds must be filled to be viable (although the converse is not true, that is, not all filled seeds are viable). **Seed viability** – the number of seeds that germinate – is more easily assessed, although it is not suitable for species that have a high level of dormancy. Seed viability can also be measured using a cut test, with the additional step of determining whether the endosperm and embryo are healthy (usually firm and white). Seed viability (including seed fill) appears to be a critical issue in Australian Rutaceae with its extreme variability in seed lot viability (Roche et al. 1997, Auld 2001).

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Little progress has been made in understanding germination of Australian Rutaceae since the study by Roche et al. (1997) and the review of Sydney species by Auld (2001). Germination of five threatened species of Rutaceae from the NSW Seedbank was very low (0–12%) when treated with Instant Smoke Plus Seed primer, with viability of 12–38% (Offord et al. 2004).

Seeds of Sydney region Rutaceae have a high level of dormancy on release from the parent (Auld 2001). Physiological dormancy is the most common type of dormancy in temperate species of Rutaceae (Baskin & Baskin 1998) indicating that the embryo has low growth potential (Baskin & Baskin 2004). A review of seed dormancy classification for shrub species in south eastern Australia assumed all Rutaceae had physiological dormancy (Ooi 2007). In some cases of physiological dormancy, germination is stimulated by gibberellic acid (GA_3) (Baskin & Baskin 2004) and GA_3 treatment is often required for laboratory germination of Rutaceae from around the world, including *Dictamnus albus*, *Diplolaena grandiflora*, *Melicope ternata* and *Ruta chalepensis* (Liu et al. 2008). Bell et al. (1993) cite unpublished studies of GA_3 enhancing germination in *Boronia fastigiata* and *Boronia megastigma*. Natural germination cues for Australian Rutaceae species include fire, heat and smoke (Paynter & Dixon 1991; Dixon et al. 1995; Roche et al. 1997; Auld 2001). A summary of treatments used to stimulate germination in previous studies on Australian Rutaceae is presented in Appendix 1.

The aim of this study was to assess seed fill and viability and improve our understanding of factors influencing laboratory-based germination of seeds in the NSW Rutaceae species. Measurements of imbibition (water uptake), embryo size and morphology, and germination responses to stimulants such as smoke water and GA_3 were recorded for some species, as a step towards classification of seed dormancy (Baskin & Baskin 2004).

Methods

The New South Wales Seedbank (located at Mount Annan Botanic Garden) currently (September 2008) stores 129 Rutaceae collections representing 93 taxa. Collections prior to 2004 comprise 46 collections (36% of all Rutaceae collections), while more recent collections since the start of the NSW Seedbank – Millennium Seed Bank partnership (2004–2008) comprise 83 collections (64%). The partnership, known as SeedQuest NSW, is an international collaborative project that has enhanced seedbanking and associated research in NSW (www.rbgsyd.nsw.gov.au/seedbank) and contributes to the global effort to conserve 10% of the world's flora as seed collections by 2010 (www.kew.org/msbp/index.htm). Seed quantities are recorded for 113 collections, with 66% comprising fewer than 1000 seeds (74 collections). Thirty-two collections (28%) have 1000–5000 seeds and only 7 collections (6%) have more than 5000 seeds. Seed fill was studied in collections made prior up to 2006; viability and germination studied in collections made between 2004 and 2006 and seed weight studied in collections made after 2005.

Data on seed weight, fill, viability and germination were collected during routine seedbanking operations. Seed weight for three replicates of 50 seeds was measured and results presented as the mean ± standard error for individual seeds. Seed fill was determined by x-ray or a cut test. The cut test was either performed on a separate seed sample to the germination test, or on seeds remaining at the conclusion of a germination test if a separate sample was not set aside due to low seed numbers. In the latter cases care must be taken in interpretation of the cut test results as a component of seed viability as seed viability may have been lost during the course of the germination test. Seed viability was determined after the germination test as the sum of the seeds that had germinated in addition to those with a firm white endosperm and embryo when assessed by a cut test. Seed fill and viability were compared using a paired one-sample *t*-test in Genstat (Lawes Agricultural Trust 2007).

Germination studies were generally conducted on dried seeds (equilibrated at 15%RH and 15°C in a dry room) although several species were studied fresh (within one month of collection and prior to drying or storage) or following freezer storage at -18°C (Table 2). The age of seeds at testing ranged from 5 days to 3.2 years (see Table 2). Germination tests were conducted on water agar (control), on water agar following 18 hrs soaking in Kings Park smoke solution at 1:100 dilution (smoke), on water agar incorporating GA_3 (250ppm), or on water agar incorporating GA_3 following 18 hrs soaking in Kings Park smoke solution at 1:100 dilution (smoke + GA_3). Due to limited seed numbers, not all seed collections received all treatments (see Table 2). All germination tests were conducted with 12 hrs light/12 hrs dark in incubators at temperatures shown in Table 2. Sample sizes for seed fill, viability and germination were dependant on the size of collections. Seeds were divided into replicates (separate Petri dishes) wherever possible.

Viability and germination data were analysed using the Generalised Linear Mixed Model analysis in Genstat (Lawes Agricultural Trust 2007), with a binomial distribution and a logit link function. Wald tests were used to determine which factors (genera, species and/or germination treatments) were significant. Wald tests are analogous to *F*-tests in ANOVA, but are used to test the significance of fixed model terms that have an asymptotic χ^2 (chi-squared) distribution (Payne 2003). A Least Significant Difference (LSD) test was used to determine which predicted means were significantly different between germination treatments. A critical *t* value ($t^{0.025}_{\text{deviance d.f.}}$) of 2 was used, as the χ^2distribution approaches 2 for increasing degrees of freedom.

Embryo type was characterised for 17 species: *Asterolasia buckinghamii*, *A. elegans*, *Boronia anemonifolia*, *B. anethifolia*, *B. ledifolia*, *B. occidentalis*, *B. serrulata*, *Eriostemon* *australasius, Geijera salicifolia, G. parviflora, Leionema dentatum, Melicope hayesii, Phebalium squamulosum* subsp. *gracile, Philotheca trachyphylla, Zieria granulata, Z. laxiflora* and *Z. prostrata*. Embryo morphology was determined by making a transverse section of seeds and assigning an embryo type according to the classification of Martin (1946).

Imbibition experiments to detect the presence of physical dormancy were conducted on *Zieria granulata, Z. laxiflora* and *Z. prostrata* as well as on two species of *Geijera* from other seedbanks (three collections of *Geijera parviflora* and one collection of *Geijera linearifolia*). For imbibition experiments, seeds were weighed, then placed on moist filter paper in Petri dishes for five minutes, removed from dishes, blotted dry and re-weighed for a measurement at time 0. Measurements were then made using the same method after 72 hours for *Geijera* species. and 122 hours for *Zieria* species. with seeds kept at room temperature during imbibition. Three replicates of 100 seeds each were used for *Zieria granulata, Z. laxiflora* and *Z. prostrata,* while six replicates of five seeds each were used for three collections of *Geijera parviflora* and one collection of *G. linearifolia.* The percentage increase in seed mass was determined using the calculation:

% increase in mass = $[(W_I - W_d)/W_d] \times 100$,

Where W_I and W_d= mass of imbibed and dry seeds, respectively (Turner et al. 2006).

Table 1: Seed weight, seed fill and threat status for Rutaceae collections from NSW Seedbank. Seed weight: average single seed weight (mg) ± SE under dry room conditions. **Seed fill**: percentage, sample size and method with G=germination, C=cut test and X=x-ray. **Threat status**: *TSC, EPBC* codes E=endangered, V=vulnerable; ROTAP codes 2=species with very restricted distribution in Australia and maximum geographic range<100km, 3=species with range >100km in Australia but only occurring in small populations, E=endangered, V=vulnerable, R=rare, C=species represented in a national park or other reserve, a=adequately reserved with total population >1000 plants, i=inadequately reserved with total populations <1000 plants, -=recorded in reserves but population size unknown (Briggs & Leigh 1988).

		Seed weight	**Seed fill**			**Threat listing**		
Accession	**Species**	**Average seed weight (mg) (±SE)**	**% filled**	**Sample size**	**Method**	**TSC**	**EPBC**	**ROTAP**
20040115	*Asterolasia buckinghamii*		100	10	G			
20020784	*Asterolasia buxifolia*		65	20	X	E		
20051377	*Asterolasia correifolia*		75	20	X			
20071235	*Asterolasia elegans*	4.35 (0.52)				E	E	2ECa
20051418	*Asterolasia hexapetala*	3.30 (0.58)	75	20	X			2RC-
20071301	*Boronia algida*	1.43 (0.58)						
20051564	*Boronia anemonifolia*		100	25	C			
20061157	*Boronia anemonifolia*							
20051507	*Boronia anethifolia*	1.61 (0.64)	96	25	C			
20051506	*Boronia boliviensis*	6.98 (1.45)				E		
873596	*Boronia falcifolia*		40	20	X			
20071238	*Boronia floribunda*	1.43 (0.41)	80	20	C			
20071309	*Boronia fraseri*	5.88 (1.20)						2RCa
20051411	*Boronia glabra*	9.04 (1.40)	100	20	X			
842476	*Boronia glabra*		50	20	X			
20051624	*Boronia ledifolia*		72	25	C			
20061206	*Boronia ledifolia*	6.51 (1.37)	60	10	C			
913622	*Boronia ledifolia*		36	11	X			
20051501	*Boronia microphylla*	1.22 (0.52)						
20051526	*Boronia microphylla*	1.16 (0.69)						
866149	*Boronia mollis*		45	20	X			
20051415	*Boronia occidentalis*	1.33 (0.47)	100	25	C			
873598	*Boronia pinnata*		50	20	X			
20061197	*Boronia repanda*	3.47 (1.43)	30	20	C	E	E	2E
20061178	*Boronia rigens*		0	20	C			
20071287	*Boronia rigens*	1.14 (0.32)						
20071166	*Boronia rosmarinifolia*	10.68 (1.80)						
20051623	*Boronia serrulata*		100	25	C			2RC-
20051625	*Boronia serrulata*		92	25	C			2RC-
20061117	*Boronia thujona*	0.96 (0.32)	100	10	C			
20061238	*Boronia thujona*	1.19 (0.26)						
20020795	*Boronia umbellata*		5	20	X	V		2VC-
20061144	*Crowea exalata*	4.84 (1.49)	50	20	C			
842663	*Crowea exalata*		80	20	X			
873436	*Crowea exalata*		25	20	X			
20051611	*Crowea saligna*	7.25 (0.93)	20	20	C			

20051612	*Eriostemon australasius*	6.06 (0.61)	20	20	C			
873599	*Eriostemon australasius*		37.5	8	X			
843027	*Eriostemon australasius* subsp. *australasius*		65	20	X			
913464	*Flindersia schottiana*		100	10	X			
20060007	*Geijera parviflora*	23.70 (1.87)	76	99	C			
872916	*Geijera parviflora*		95	20	X			
872921	*Geijera parviflora*		100	20	X			
890212	*Geijera parviflora*		100	20	X			
923903	*Geijera parviflora*		100	20	X			
923862	*Geijera salicifolia*		100	20	X			
863021	*Halfordia kendack*		100	20	X			
20061168	*Leionema carruthersii*	2.48 (1.29)	10	20	C			3RC-
20051626	*Leionema dentatum*		100	35	C			
877288	*Leionema dentatum*		90	20	X			
20061119	*Leionema diosmeum*	1.81 (0.36)	90	20	C			
20051190	*Leionema elatius* subsp. *beckleri*	1.12 (0.73)	20	20	C			
20051491	*Leionema lamprophyllum*	1.03 (0.54)						
20071259	*Leionema ralstonii*	4.44 (1.12)				V	V	2VCi
20061203	*Leionema rotundifolium*	4.94 (1.26)	40	10	C			3RC-
20020916	*Leionema* sp. Colo River (P.H. Weston 2423)		50	20	X			
850823	*Melicope elleryana*		100	20	X			
873898	*Melicope hayesii*		30	20	X			
861402	*Melicope micrococca*		60	20	X			
20051369	*Nematolepis squamea*		55	20	X			
20071271	*Phebalium bifidum*	3.52 (0.82)						
20051447	*Phebalium glandulosum* subsp. *glandulosum*	1.71 (0.22)	100	10	G			
20051470	*Phebalium nottii*	3.02 (1.06)	85	20	X			
20051481	*Phebalium obcordatum*	2.18 (0.83)	100	10	G			3RCa
20051407	*Phebalium squamulosum* subsp. *gracile*	2.63 (0.86)	75	20	G			
933424	*Phebalium squamulosum* subsp. *gracile*		85	20	C			
20051474	*Phebalium stenophyllum*	2.90 (0.89)	100	10	G			
20051198	*Philotheca buxifolia*		16	25	C			
20051426	*Philotheca ciliata*	3.90 (1.38)	79	19	X			
20051448	*Philotheca difformis*	3.45 (0.91)	5	20	X			
864893	*Philotheca difformis* subsp. *difformis*		0	20	X			
873451	*Philotheca difformis* subsp. *difformis*		15	20	X			
20051490	*Philotheca ericifolia*	1.94 (0.65)	100	10	G	V	V	3RC-
20051197	*Philotheca hispidula*	10.51 (2.70)	100	20	G			
20051195	*Philotheca myoporoides*	7.43 (1.43)	70	20	X			
20051422	*Philotheca salsolifolia*	7.81 (1.15)	90	20	X			
20071043	*Philotheca scabra*	9.98 (1.47)						
20061167	*Philotheca trachyphylla*	4.44 (1.15)	64	14	C			
842876	*Philotheca trachyphylla*		75	20	X			
20061122	*Zieria arborescens*	1.35 (1.05)	84	150	C			
20061172	*Zieria buxijugum*	0.89 (0.39)	10	20	C	E	E	2E
20051419	*Zieria cytisoides*	3.11 (0.51)	90	20	X			
20061171	*Zieria formosa*	0.99 (0.40)	15	20	C	E	E	2E
20041359	*Zieria granulata*		100	30	C	E	E	2VCi
20061125	*Zieria ingramii*		0	20	C	E	E	2V
20071243	*Zieria ingramii*	3.80 (1.22)				E	E	2V
20071233	*Zieria involucrata*	1.67 (0.64)				E	V	2VCa
20020783	*Zieria involucrata*		55	20	X	E	V	2VCa
20051605	*Zieria laevigata*	3.19 (1.01)	68	25	C			
20041352	*Zieria laxiflora*		100	28	C			
20061175	*Zieria littoralis*	1.85 (0.67)	90	20	C			
20061173	*Zieria parrisiae*	1.21 (0.77)	30	20	C	E	E	2E
20061174	*Zieria parrisiae*		5	20	C	E	E	2E
20071312	*Zieria pilosa*	3.31 (0.83)						
913530	*Zieria pilosa*		65	20	X			
20071159	*Zieria prostrata*	1.29 (0.73)				E	E	2E
20020791	*Zieria prostrata*		67	30	C	E	E	2E
20061152	*Zieria smithii*	1.19 (0.62)	90	10	C			
20061164	*Zieria smithii*	1.69 (0.19)	80	20	C			
20071158	*Zieria smithii*	1.28 (0.65)						
923860	*Zieria smithii*		80	20	X			
20061189	*Zieria southwellii*	1.36 (0.55)	90	20	C			

Results

We quantified seed fill and/or viability and germination for 112 Rutaceae species. Seed weights (recorded for 56 species) were highly variable (Table 1), e.g. in the Tribe Boronieae there was an order of magnitude difference between the smallest (*Zieria buxijugum*) and largest (*Boronia rosmarinifolia*). *Geijera parviflora*, the only representative of the tribe Zanthoxyleae in this study, was the largest at 23.7 mg. There is considerable variation in seed weight even within a genus, e.g. *Boronia thujona* (0.96 mg) compared to *Boronia rosmarinifolia* (10.68 mg) or *Philotheca ericifolia* (1.94 mg) compared to *Philotheca hispidula* (10.51 mg).

At the generic level *Philotheca* had the largest seeds (mean seed weight of 8 species was 6.18 mg se=1.12), then *Boronia* (15 species) 3.6 mg se=0.85, *Phebalium* (6 species) 2.66 mg se=0.26, *Leionema* (6 species) 2.63 mg se=0.68 and *Zieria* (15 species) 1.87 mg se=0.24.

Seed fill was highly variable ranging from none to 100%, even between different collections of the same species (Table 1). Collections with no filled seed were made from *Boronia rigens*, *Philotheca difformis* subsp. *difformis* and *Zieria ingramii*#. Low seed fill (≤30%) was recorded for *Boronia repanda*#, *B. umbellata*#, *Crowea exalata* (1 of 3 collections studied), *C. saligna*, *Eriostemon australasius* (1 of 2 collections), *Leionema carruthersii*#, *L. elatius* subsp. *beckleri*, *Melicope hayesii*, *Philotheca buxifolia* subsp. *buxifolia*, *P. difformis* (3 of 3 collections), *Zieria buxijugum*, *Z. formosa*# and *Z. parrisiae*# (2 of 2 collections). Seed fill was generally significantly higher than seed viability ($P<0.001$). Low seed fill was more prevalent (44%) in threatened species# than in common species (15%). (# indicates species listed under the NSW *Threatened Species Conservation* Act, Federal *Environmental Protection Biodiversity Conservation* Act or as *Rare or Threatened Australian Plants*.)

Viability data was pooled and averaged across germination treatments, as there was no significant difference in viability between treatments at the end of germination tests. Viability of filled seeds was highly variable (0–97%), with 80% of collections having low viability (<75%) (Table 2). Low viability was found in all 11 threatened species tested, with only one (*Zieria granulata*) having viability >60%.

Similar germination results were recorded for both threatened and common species, with about half the collections germinating well (>80%) when given one or more treatments. Percent germination across the treatments was significantly different ($P<0.001$), with GA_3 in combination with smoke water (average 62% germination) > GA_3 (40%) > no treatment (13%) or smoke treatment (9%) (Table 2). These results indicate that a proportion of seeds are non-dormant at the time of testing as germination of untreated seed can occur, albeit at a low level. A greater proportion has non-deep physiological dormancy, with germination stimulated by GA_3.

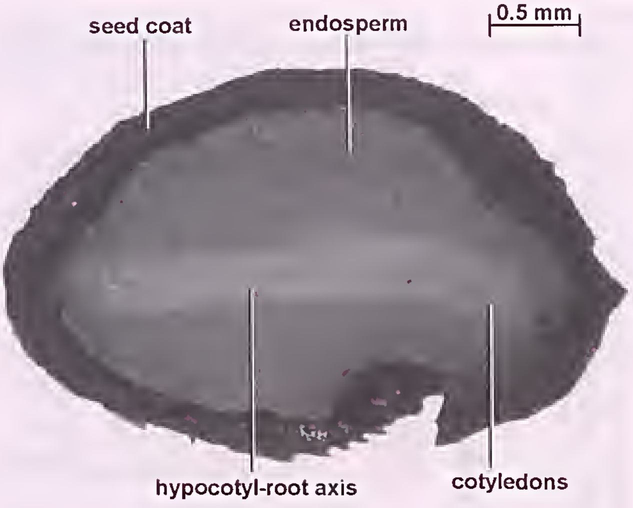

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Fig. 1. *Zieria laxiflora* seed showing linear embryo (root axis and cotyledons).

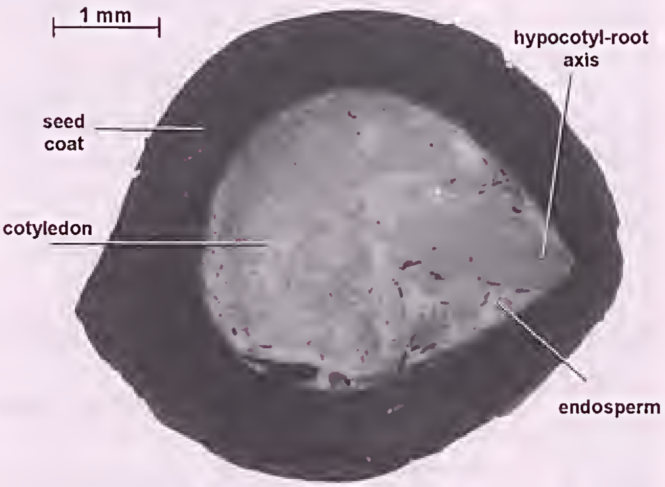

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Fig. 2. *Geijera salicifolia* var. *latifolia* seed showing spathulate embryo (hypocotyl-root axis and cotyledon).

Water was imbibed by all five species examined, with increases of 30–51% for *Zieria* species and 45–58% for *Geijera* species (Table 3). In a separate study, seeds of five *Boronia* species (*B. anemonifolia*, *B. anethifolia*, *B. ledifolia*, *B. serrulata* and *B. occidentalis*) were found to imbibe water with an increase in seed weight of 16–34% over 72 hrs (A. Martyn, unpublished data). Imbibition is a prerequisite for germination and germination occurred without scarification in 34/38 species tested (Table 2) indicating that physical dormancy was not present. Embryos were fully developed in all 17 species, with linear embryos for all species (for example, *Zieria laxiflora*, Figure 1) except *Geijera parviflora* and *G. salicifolia* var. *latifolia* (Figure 2) which have spathulate embryos.

Table 2: Seed age, germination conditions, viability, final germination and time to germination for Rutaceae collections from NSW Seedbank. Germination conditions: storage conditions prior to germination test, seed age, day and night temperature during germination test (all with 12 hrs light/12 hrs dark), seeds per replicate and number of replicates. Viability: percentage ± SE averaged at end of all germination treatments. Germination data: percentage of viability adjusted germination (VAG) ± SE for untreated (control), smoke, gibberellic acid (GA3) and smoke+GA3 treated seeds. Bold indicates significantly difference to untreated seeds. Time to germination: time to 1st (T 1st) and last (T last) germination in days for all successful treatments.

									Viability of germination % ± se					Time (days)		
Accession	Species	Conditions prior to germ	Seed Age (days)	Day Temp (°C)	Night Temp (°C)	Seeds per replicate	No of replicates	Av viable seed (%) (±SE)	no treatment	Smoke	GA3	Smoke +GA3	no treatment	Smoke	GA3	Smoke +GA3
20040115	*Asterolasia buckinghamii*	dry room	1160	27	12	10	1	50				0				
20051377	*Asterolasia correifolia*	dry room	505	27	12	15	2	39 (0.8)	0 (0)			**81** (2.1)				28–98
20051418	*Asterolasia hexapetala*	dry room	499	27	12	10	2	55 (2.7)	52 (3.2)			**100** (0)	158–338			42–294
20051564	*Boronia anemonifolia*	dry room	245	25	15	25	3	97 (0.8)	4 (1.6)	**26** (1.3)	19 (1.2)	**38** (1.7)	72–135	53–200	42–188	43–125
20061157	*Boronia anemonifolia*	fresh	43	20	10	25	3	69 (1.3)	9 (0.9)			**27** (1.7)	89–96			38–80
20051507	*Boronia anethifolia*	dry room	465	27	12	20	3	87 (1.6)	6 (1.4)			**64** (1.8)	17			14–66
20051506	*Boronia boliviensis*	dry room	472	27	12	9	1	56				80				34–83
20051411	*Boronia glabra*	dry room	499	27	12	10	2	68 (1.6)	0 (0)			**100** (0)				22–42
20051526	*Boronia microphylla*	dry room	463	27	12	10	2	20 (1.9)	0 (0)			**100** (0)				133–200
20051501	*Boronia microphylla*	dry room	474	27	12	10	1	30				100				34–63
20051415	*Boronia occidentalis*	dry room	492	33	18	20	3	73 (1.6)	7 (0.6)	2 (1.2)		**74** (1.4)	96	206		35400
20061117	*Boronia thujona*	dry room	5	27	12	10	1	40	25	75		100	217	105–217		26–61
20061144	*Crowea exalata*	dry room	244	27	12	5	5	8 (1.6)	67			**100**	184			265
20051611	*Crowea saligna*	dry room	538	27	12	10	2	0 (0)								
20051612	*Eriostemon australasius*	dry room	523	27	12	15	2	2 (0.8)								
20060007	*Geijera parviflora*	dry room	239	27	12	25	3	80	0							
20051626	*Leionema dentatum*	dry room	509	27	12	15	2	5 (0.8)	50 (5.9)			**100**	155			
20061119	*Leionema diosmeum*	dry room	252	27	12	14	1	39	17			80	75			115–164
20051190	*Leionema elatius* subsp. *beckleri*	dry room	526	27	12	12	2	6 (1.0)					121–184			
20061203	*Leionema rotundifolium*	dry room	229	27	12	15	1	30	60			25	164			70
20051369	*Nematolepis squamea*	dry room	506	27	12	15	2	50 (1.1)	65 (1.2)			**88** (3.0)	57–121			42–124
20051447	*Phebalium glandulosum* subsp. *glandulosum*	dry room	490	27	12	10	1	30				33				133
20051470	*Phebalium nottii*	dry room	482	27	12	10	2	75 (1.3)	0 (0)			**28** (2.0)				36–63
20051481	*Phebalium obcordatum*	dry room	481	27	12	10	1	50				0				
20051407	*Phebalium squamulosum* subsp. *gracile*	dry room	499	27	12	10	2	35 (0.0)	0 (0)			**63** (3.0)				27–59
20051474	*Phebalium stenophyllum*	dry room	482	27	12	10	1	10				100				207
20051426	*Philotheca ciliata*	dry room	497	27	12	15	2	63 (2.4)	0 (0)	6 (2.1)	**58** (3.5)	**67** (3.5)		154	23–110	28–144
20051448	*Philotheca difformis*	dry room	488	27	12	10	2	0 (0)								
20051490	*Philotheca ericifolia*	dry room	475	27	12	10	1	20				100				49–133

20051197	*Philotheca hispidula*	dry room	514	27	12	10	2	5 (1.9)	0			0				
20051195	*Philotheca myoporoides*	dry room	514	27	12	10	2	20 (1.9)	50			**0** (0)	64–121			
20051422	*Philotheca salsolifolia*	dry room	497	27	12	10	2	43 (0.9)	47 (3.1)	29		**75** (4.2)	201–204	120–183		120
20061167	*Philotheca trachyphylla*	dry room	239	27	12	10	1	10				100				83
20061122	*Zieria arborescens*	fresh	54	27	12	25	3	82 (2.3)	5 (1.3)	4 (1.3)	**54** (3.3)	**63** (3.1)	166–176	191–262	47–273	41–166
20061172	*Zieria buxijugum*	dry room	238	27	12	20	1	0								
20051419	*Zieria cytisoides*	dry room	498	27	12	10	2	85 (1.9)	0 (0)			**73** (1.1)				34–73
20061171	*Zieria formosa*	dry room	238	27	12	20	1	25	25			100	265			26–61
20041359	*Zieria granulata*	dry room	854	27	12	10	2	42 (2.6)	8 (2.4)			**63** (1.5)	23			28–49
20041359	*Zieria granulata*	freezer	267+366	20	20	20	3	70 (1.5)	2 (1.2)		**44** (0.9)		29		21–369	
20041352	*Zieria laxiflora*	dry room	867	27	12	10	2	80 (2.7)	33 (2.7)			**82** (1.7)	23–182			28–120
20041352	*Zieria laxiflora*	freezer	280+379	20	20	20	3	68 (1.5)	0 (0)		**29** (1.3)				21–210	
20061175	*Zieria littoralis*	dry room	238	27	12	10	5	76 (1.6)	75 (2.2)			**100** (0)	44–291			26–87
20061173	*Zieria parrisiae*	dry room	238	27	12	10	5	27 (1.7)	5			**100** (0)	40			71–124
20061152	*Zieria smithii*	dry room	242	27	12	5	5	62 (0.9)	23 (1.7)			**93** (1.7)	212			47–112
20061164	*Zieria smithii*	dry room	239	27	12	10	5	86 (1.0)	0 (0)							

Table 3: Percentage imbibition (average % increase in seed weight ± SE) for seven seed collections (five Rutaceae species).

	Imbibition (%)	
Species	**Average**	**Std error**
Zieria granulata	30.3	2.0
Zieria prostrata	51.3	3.0
Zieria laxiflora	33.7	1.7
Geijera parviflora 1	58.5	10.8
Geijera parviflora 2	45.4	8.0
Geijera parviflora 3	53.1	12.7
Geijera linearifolia	45.4	19.1

Discussion

Implications for seedbanking

This study confirms that seed fill, viability and germination are highly variable in NSW Rutaceae, as observed in previous studies from Western Australia (Roche et al. 1997) and the Sydney region (Auld 2001). To ensure optimal regeneration of plants from both conservation seedbanks that aim for long-term seed storage, and restoration seedbanks that have more rapid turnover of seed collections, it is necessary to take these issues into account. For example to plan collecting trips over several seasons to enable the collection of sufficient seeds for germination, or use sufficient seeds in viability and germination tests to account for the presence of empty seeds in a collection.

Distinguishing between seed fill and viability may assist in determining whether problems are occurring in the seed banking or regeneration stage, as seed fill is a fixed characteristic for a collection, while viability will be maximal at collection and decline during storage. Problems with seed fill occur before natural dispersal or seed collection and can be an inherent species characteristic, the result of inbreeding depression in small populations, or a result of seed predation or environmental conditions such as prolonged drought impacting on pollination or seed development (reviewed by Fenner & Thompson 2005). Predation had a significant impact on seed fill for *Zieria laevigata* and *Zieria prostrata* with up to 50% of seeds lost to predators for both species in some locations (Armstrong 2002, NSW NPWS 1998). Further study of seed production and pre-dispersal seed losses over several years (as suggested by Auld 2001), is needed especially for threatened species such as *Zieria parrisiae*.

Our results indicate that threatened species were more likely to have low seed fill than common species, though viability and germination were similar. This suggests that poor seed fill is a contributing factor to threat status. Observations of seed or fruit presence (e.g. Shapcott et al. 2005) may significantly overestimate reproductive activity if seed fill is not taken into account.

Problems with seed viability can be minimised by ensuring seeds are collected as close to maturity as possible (including bagging seeding branches if practical), followed by thorough cleaning, appropriate storage (cool dry conditions) and monitoring of viability during storage (Smith et al. 2003). Studies of seed viability during conservation storage are also required for the Rutaceae family, as little information is available (studies on seed persistence in soil do not necessarily relate to seed viability in storage). A study on the Western Australian Rutaceae species *Geleznowia verrucosa* measured a decline of 10–11% viability in only 175 days at room temperature (Paynter & Dixon 1990). Determining and maintaining seed viability is a key factor not only in seedbanking but also in utilization of seeds for restoration (Thompson et al. 2001).

The Rutaceae seeds examined have physiological dormancy (according to the definition of Baskin & Baskin 2004) as they are capable of imbibing water (ruling out physical dormancy), have fully developed embryos (ruling out morphological dormancy) and respond to germination stimulants such as GA_3. Results of this study and others (e.g. Ooi 2007) refute the suggestion that the seed coat may act as a physical barrier to imbibition in Rutaceae (Auld 2001). Imbibition experiments should be conducted for a wider range of Rutaceae species, to consolidate these results. It is important to note that imbibition studies should be conducted over a period of at least 72 hrs, as the time course of some previous studies has been too short (e.g. 5 hrs, Mildenhall 2002).

Germination of Rutaceae seeds can be significantly improved using a combination of smoke and GA_3. Two important processes conducted in *ex situ* seed banks, namely assessing seed viability using germination, and growing plants from seed for recovery of threatened species, could potentially be enhanced by the use of this treatment. The additive effect of smoke and GA_3 increases germination for some crop species (van Staden et al., 2000; Kępczyński et al., 2006) and several Australian native species (Cochrane et al. 2002). Little is known about the role, timing and location of gibberellin activity in relation to environmental cues for germination, particularly for seeds from wild-sourced species, however evidence suggests that smoke may increase the sensitivity of seeds to gibberellins and other hormones (van Staden et al., 2000; Schwachtje & Baldwin 2004)

Implications for seed ecology

Classification of seed dormancy offers a structured approach to collecting basic information on seed characteristics and can help identify likely factors required for dormancy break. For example, the physiological dormancy identified in this study may be broken by seasonal temperature changes, dry afterripening, stratification and wetting and drying cycles (Merritt et al. 2007). These natural cues may have been acting when regeneration of the following species was noted without passage of a fire: *Asterolasia elegans* (Benson & McDougall 2001), *Boronia coerulescens* subsp. *coerulescens* and *B. filifolia* (Bonney 2003), *Leionema lachnaeoides* (NSW NPWS 2001), *Zieria lasiocaulis* (NSW NPWS 2002) and *Zieria granulata* (Department of Environment & Conservation 2005).

The extrapolation of laboratory germination outcomes to germination in nature has some limitations. Storage conditions and seed age can affect subsequent germination (Baskin, Thompson & Baskin 2006). For example, seeds may experience afterripening in dry room storage prior to germination. However, for many species there has been little opportunity to study fresh seeds and laboratory based studies on stored seeds, along with dormancy classification, provide a starting point for further investigations.

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Appendix 1

Treatment	Species with positive germination response	Reference	Species with negative or no germination response	Reference
Scarification or seed coat removal	*Geleznowia verrucosa*	Paynter & Dixon 1991	*Boronia, Eriostemon, Zieria, Phebalium*	Whitehorne & McIntyre 1975
	Geijera linearifolia, Eriostemon angustifolius subsp. *angustifolius*	Bonney 2003	*Leionema lachnaeoides*	Mildenhall 2002
Leaching	*Boronia ledifolia*	Benson & McDougall 2001	*Geleznowia verrucosa*	Paynter & Dixon 1991
	Geijera linearifolia, Eriostemon angustifolius subsp. *angustifolius*	Bonney 2003		
Scarification or seed coat removal + leaching	*Boronia ledifolia, B. denticulata*	Whitehorne & McIntyre 1975		
	Crowea saligna, C. exalata	Whitehorne & McIntyre 1975		
	Eriostemon australasius	Langkamp 1987		
	Geijera parvifolia	Whitehorne & McIntyre 1975		
	Zieria smithii	Whitehorne & McIntyre 1975		
Gibberellins	*Phebalium daviesii*	Lynch & Appleby 1996		
	Boronia fastigiata, B. megastigma	Bell et al. 1993		
Smoke or smoke products	*Boronia fastigiata, B. megastigma, B. tenuis, B. viminea*	Roche et al. 1997	*Boronia fastigiata*	Dixon et al. 1995
	Crowea saligna	Langkamp 1987	*Boronia spathulata*	Roche et al. 1997
	Diplolaena dampieri and Geleznowia verrucosa	Roche et al. 1997	*Correa reflexa* var. *cardinalis*	Roche et al. 1997
	Geleznowia verrucosa	Dixon et al. 1995	*Leionema lachnaeoides*	Mildenhall 2002
	Philotheca spicata	Dixon et al. 1995	*Phebalium anceps*	Dixon et al. 1995
Heat	*Asterolasia elegans*	Auld 2001	*Leionema lachnaeoides*	Mildenhall 2002
	Boronia ledifolia	Auld 2001		
	Eriostemon australasius	Auld 2001		
	Leionema	Auld 2001		
	Zieria arborescens, Z. involucrata, Z. laevigata	Auld 2001		

Population diversity of *Doryanthes excelsa* (Doryanthaceae) in eastern Australia

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Abstract: The population diversity of *Doranthes excelsa* Corrêa (Doryanthaceae) was measured from nine distinct geographic populations across eastern Australia, using random amplified polymorphic DNA (RAPD) markers. An UPGMA dendrogram of individuals was derived from squared Euclidian distances based on the Dice (1945) algorithm. Three clusters corresponding to populations at Somersby, Newfoundland and Kremnos Creek populations were found to be distinct from the remainder of the sampled individuals. A Φ_{ST} value of 0.443 indicated that a significant diversity between geographic populations existed; this appeared to be a product of geographical distance and isolation between some of the populations. (PCR = Polymerase Chain Reaction; RAPD = Random Amplified Polymorphic DNA)

The results suggest that there is lesser gene flow between the 'northern' populations (Kremnos Creek and Newfoundland) when compared to the 'southern' populations and that they have a significant level of genetic isolation. The two 'northern' populations should therefore be regarded as being of considerable value for conservation authorities and the commercial breeding sector and should be given priority for conservation. The plants there appear to exhibit a smaller phenotype but confirming this requires further quantification.

Keywords: *Doryanthes*, Doryanthaceae, population, DNA, RAPD, polymorphism.

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Introduction

Doryanthes excelsa Corrêa (family Doryanthaceae), Giant Lily or Gymea Lily, is a spectacular and morphologically distinctive monocotyledon endemic to the open sclerophyll *Eucalyptus* forests of the Central Coast and North Coast of New South Wales, Australia. It is distributed discontinuously from near Wollongong in the south to the hinterland of Coffs Harbour in the north but there as a large gap between the central coast and northern populations. The species develops ensiform leaves to a height of approximately 2 m and inflorescences up to 4 m tall, holding up to 150 large, red flowers (Newman 1928). Because of their size *Doryanthes excelsa* inflorescences are used in large floral displays in hotel foyers, churches, airports and shopping centres (Burchett et al. 1989).

Doryanthes excelsa is highly prized domestically by the Australian floricultural industry and has considerable economic potential as a high-value, cut-flower export crop (Smith 2000). It is also increasingly sought as a landscape plant. At present, many of these cut-stems are sourced from wild populations under licence, or from a very limited number of small-scale plantations. The combination of its high-value and limited supply has led to the illegal harvesting of flowers and theft of seed from wild populations, potentially threatening the long-term sustainability of the species. Urbanisation has also resulted in the destruction of populations.

In order to promote a sustainable cut-flower industry for this species, and to conserve existing wild populations, a novel micropropagation system using immature inflorescences as the explant source has been developed (Dimech *et al.* 2007). The ability to initiate both shoot organogenesis and callogenesis in *Doryanthes excelsa* will form the basis of a viable and environmentally-sustainable industry in the foreseeable future. The development of improved cultivars with desirable commercial traits could add significant value to the crop; molecular breeding programs are likely be reliant upon the identification of novel genes from wild populations.

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Given this, there is both a conservation and commercial purpose to measuring the population diversity of this species. Initially, locating sources of variability within wild populations would improve basic understanding of the source and distribution of genetic variability (and potential novel traits) where no research has been performed previously. The aims of this study were to measure the molecular diversity of *Doryanthes excelsa* individuals from nine distinct geographic populations and derive a value of genetic differentiation for wild populations; determine the conservation value of two isolated northern populations and identify sources of diversity that may be useful for future breeding programs.

Materials and Methods

Collection of plant material and sampling procedure

Leaf samples from 87 *Doryanthes excelsa* plants were collected from nine locations (i.e. populations) across the natural range of the species in New South Wales (Table 1, Figure 1). At each location a linear transect was established and plants sampled approximately every 4 m. The intention was to sample ten plants at each site but only eight samples were obtained at Somersby and 9 at Nelsons Bay. As an "out-group", a leaf sample of *Doryanthes palmeri* was collected from a single specimen of unknown provenance growing at the Royal Botanic Gardens Melbourne. Elevation, longitude and latitude were recorded using a global positioning system. Samples were collected in July 2003. In all cases, immature and semi-chlorophyllous leaf material was harvested from the centres of leaf whorls, and placed in resealable polyurethane bags and stored at 4°C in the field, then put into long-term storage at –70°C within a week of collection. Leaf and flower specimens were lodged with the National Herbarium of Victoria (Melbourne).

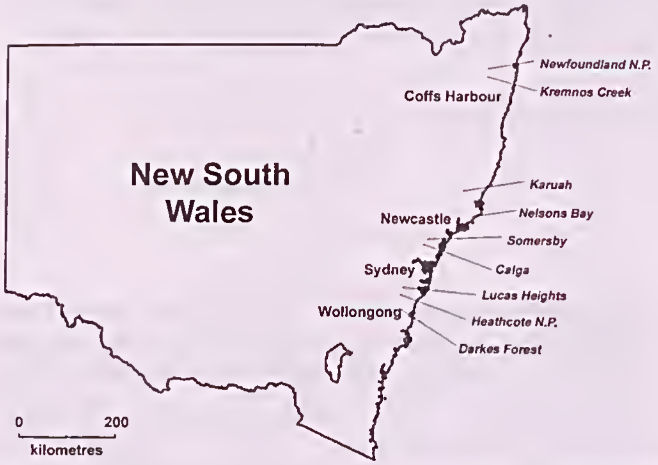

Fig. 1. Collection sites for Doryanthes excelsa populations used in this study.

Extraction of DNA

Frozen leaf material was ground into a powder under liquid nitrogen and the remaining fibres were removed manually. Total genomic DNA was extracted from 20–30 ng of powdered tissue using the Dneasy® Plant Mini Kit (Qiagen, Australia) following the full procedure as detailed in the handbook (January 2004 edition). DNA yield and quality was comparatively quantified with 100 ng μl^{1} *Escherichia coli* DNA standards in 1.4% (w/v) agarose gels. Final working solutions of 20 ng μl^{-1} were prepared by diluting concentrated *D. excelsa* DNA stocks in distilled, deionised water. Samples were stored at -20°C.

RAPD PCR Amplification

DNA fragments were amplified using 10-mer oligonucleotide primers (Sigma-Genosys, Australia) selected from the 'Operon' series. Sixty primers were screened for *D. excelsa* and the 10 most informative were used across the entire population, these being A1 (5'-CAGGCCCTTC), A20 (5'-GTTGCGATCC-3'), B8 (5'-GTCCACACGG-3'), B10 (5'-CTGCTGGGAC-3'), C9 (5'-CTCACCGTCC-3'), C11 (5'-AAAGCTGCGG-3'), E1 (5'-CCCAAGGTCC-3'), H8 (5'-GAAACACCCC-3'), J6 (5'-TCGTTCCGCA-3') and K15 (5'-GAGCGTCGAA-3').

Table 1. *Doryanthes excelsa* **populations sampled (in geographic order from north to south) and the number of samples (n) of each. Population distances are calculated using the Haversine Formula (Sinott 1984).**

Population	Code	*n*	Longitude	Latitude	Elevation (m)	Distance to nearest population (km)
Newfoundland	H	10	153° 06'	29° 53'	140	17
Kremnos Creek	E	10	152° 58'	29° 59'	86	17
Karuah	D	10	152° 00'	32° 38'	43	16
Nelsons Bay	G	9	152° 07'	32° 44'	43	16
Somersby	J	8	151° 15'	33° 22'	163	5
Calga	A	10	151°13'	33° 24'	211	5
Lucas Heights	F	10	150° 59'	34° 02'	159	3
Heathcote N.P.	C	10	150° 59'	34° 04'	152	3
Darkes Forest	B	10	150° 56'	34° 14'	380	19

Polymerase chain reaction (PCR) was performed in a volume of 25 µl containing a total of 50 ng of genomic DNA, 2.5 µl of 10× PCR Buffer (200 mmol l^{-1} of Tris-HCl and 500 mmol l^{-1} KCl, pH 8.4; Invitrogen, Australia), 3.6 mmol l^{-1} of $MgCl_2$, 240 µmol l^{-1} of dNTPs, 0.8 µmol l^{-1} of primer and 1 U (0.2 µl) of *Thermus aquaticus* DNA polymerase (Invitrogen, Australia). The amplification reaction consisted of an initial denaturation step of 94°C for 1 min, followed by 35 cycles of denaturing at 94°C for 30 s, annealing at 45°C for 30 s and extension at 72°C for 1 min. A final extension of 72°C for 5 min completed the reaction. Where individual bands did not reproduce, the data were excluded. All experiments were performed twice to ensure reproducibility (He *et al* 1994).

Amplification products were separated on a 1.4% (w/v) agarose gel for 2 h at 90 V in TAE buffer. The products were stained using SYBR® Green I dye and fragments within the range 350–2700 bp were observed under UV-light (λ=620 nm), and photographed using the Kodak *1D* computer programme

Data analysis

Statistical analyses of RAPD patterns were based on the following assumptions: (*i*) that RAPD fragments were diploid and dominant markers with loci being either present (amplified and scored as '1') or absent (non-amplified and scored as '0'); (*ii*) that the co-migration of fragments indicated identical loci and (*iii*) that polymorphic loci were subject to Mendelian inheritance. RAPD data were manually entered into a binary data file. Genetic distances between individuals were calculated using the Dice (1945) similarity coefficient and were subjected to Unweighted Pair-Grouped Method with Arithmetic Means Analysis (UPGMA) clustering using the *SAS* (SAS Institute, USA) statistical package. An UPGMA dendrogram was derived from Euclidian distances, calculated as [1-Dice coefficient]. A two-dimensional ordination was created using the non-metric multidimensional scaling (NMDS) procedure in *SAS* version 9.1.3 with the default options apart from formula=2 dim=2 and fit=2.

Divergence between populations was estimated as Φ_{ST} and tested by Analysis of Molecular Variance (AMOVA) using *GenAleEx 6.1* (Peakall and Smouse 2006). A two-way AMOVA was used to measure the spread of molecular variance between and within all sampled populations of *Doryanthes excelsa* as well as the 'northern' and 'southern' populations in isolation. A three-way AMOVA was used to indicate the levels of molecular variance at the regional ('northern' and 'southern') and population levels. A spatial structure analysis was performed using *GenAleEx 6.1* (Peakall and Smouse 2006) to test whether isolation was correlated with geographical distance. In all analyses, statistical significance was indicted where p<0.05.

Results

Ten RAPD primers produced a total of 103 scorable fragments across 87 individuals. The number of bands produced with each RAPD primer ranged from 5 to 14 and were between 350 bp and 2700 bp in size. The number of polymorphic loci measured across all individuals was 91 (88.4%).

Table 2 a) Three-level Analysis of Molecular Variance (AMOVA) indicating molecular variance amongst and between regions and populations of *Doryanthes excelsa*. df = degrees of freedom; SS = sum of squares; MS = mean of squares.

Source	df	SS	Estimated Variance	Percentage Variance	Φ	Probability
Regions	1	1.031	0.024	18%	0.180	<0.001
Populations within Regions	7	2.068	0.022	17%	0.201	<0.001
Within Populations	78	6.722	0.086	65%	0.345	
Total	86	9.891	0.132			

b) Two-way AMOVA indicating the percentages of molecular variance amongst and between the two 'northern' populations of *Doryanthes excelsa.*

Source	df	SS	MS	Estimated Variance	Percentage Variance	Φ	Probability
Populations	1	0.532	0.532	0.044	32%		
Within Populations	18	1.674	0.093	0.093	68%	0.321	0.000
Total	19	2.206	0.625	0.137			

c) AMOVA indicating the percentages of molecular variance amongst and between the 7 'southern' populations of *Doryanthes excelsa.*

Source	df	SS	MS	Estimated Variance	Percentage Variance	Φ	Probability
Populations	6	1.536	0.256	0.018	18%		
Within Populations	60	5.048	0.084	0.084	82%	0.176	0.000
Total	66	6.584	0.340	0.102			

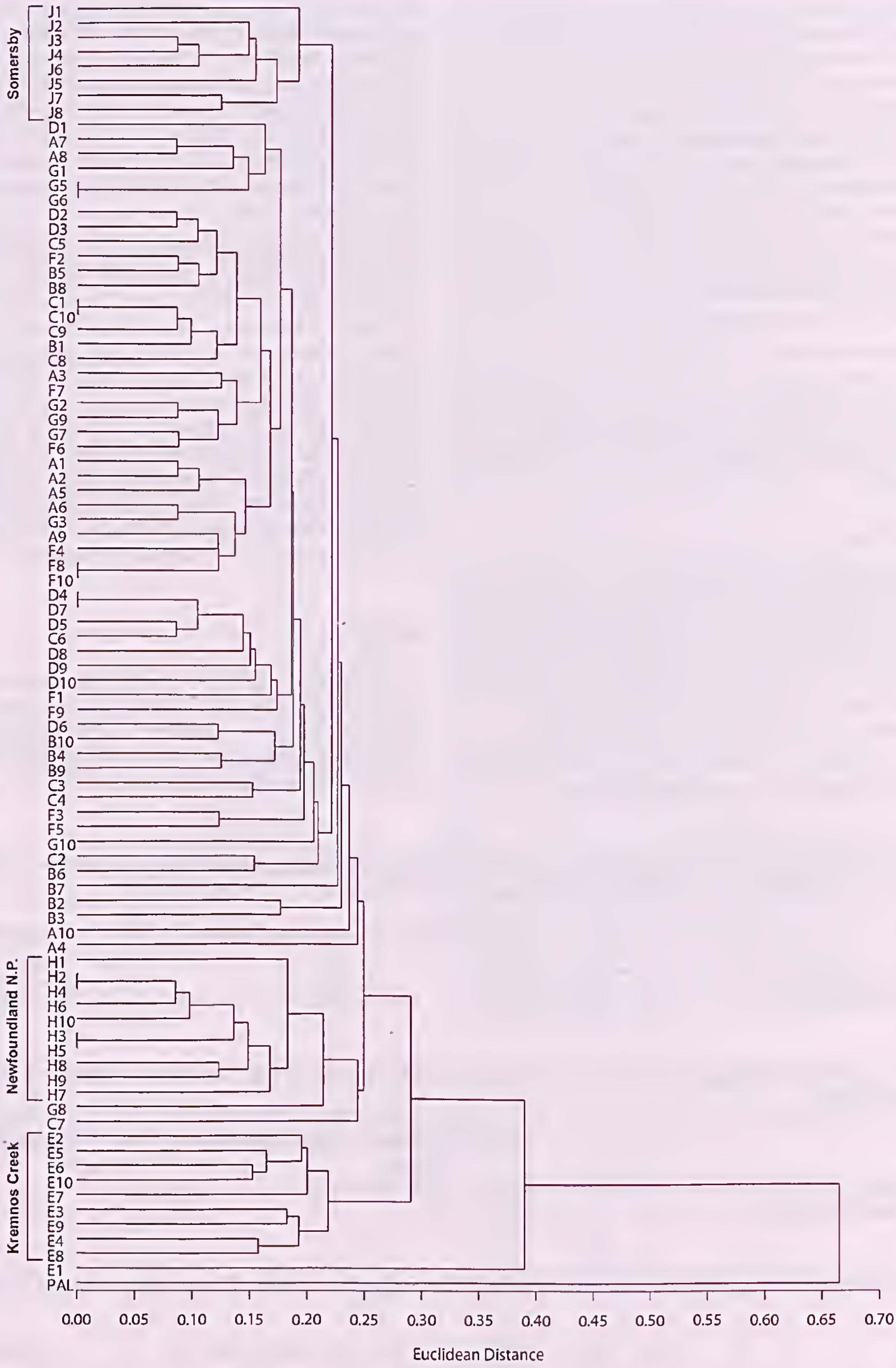

Fig. 2. An UPGMA dendrogram showing the squared Euclidian distances of the individuals from the nine *Doryanthes excelsa* populations. Each individual is labelled with a two-letter prefix indicating the population, and a numeric accession number. A=Calga; B=Darkes Forest; C= Heathocote National Park; D=Karuah; E=Kremnos Creek; F=Lucas Heights; G=Nelsons Bay; H=Newfoundland State Forest; J=Somersby; PAL=*Doryanthes palmeri* (for comparison).

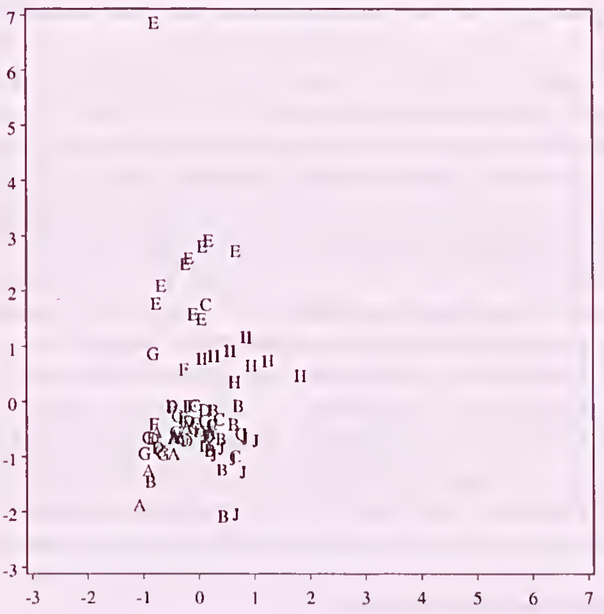

Fig. 3. A two-dimensional NMDS ordination showing the relationship between individuals in nine populations of *D. excelsa.* A=Calga; B=Darkes Forest; C= Heathcote National Park; D=Karuah; E=Kremnos Creek; F=Lucas Heights; G=Nelsons Bay; H=Newfoundland State Forest; J=Somersby. The distance $\text{stress}_2 = 0.165$.

The greatest genetic distance between any two individuals was 0.044 for E1/J1 as well as B3/J8. The genetic distance of 0.00 between individuals was found between D4/D7; G5/G6; C1/C10; F8/F10; H3/H4 and H2/H5, indicating that these individuals may be clones.

An UPGMA dendrogram (Figure 2) shows three clusters corresponding to the Somersby (J) and Newfoundland (H) populations and 9 of the 10 Kremnos Creek (E) individuals. The remaining Kremnos Creek individual (E1) was distinct from all other samples including *Doryanthes palmeri* (PAL), though it was closest to the other Kremnos Creek individuals. The remainder of individuals and populations did not obviously cluster according to geographic distribution.

A two-dimensional NMDS ordination (Figure 3) demonstrated the diversity of *Doryanthes excelsa* across the nine populations (*Doryanthes palmeri* was not included because the large distance between it and the *D. excelsa* individuals). The picture is very similar to that shown by cluster analysis: the Newfoundland State Forest (H) and Kremnos Creek (E) populations were distinct and the Somersby (J) population lay slightly to the right of the remaining individuals but was overlapping with the other central coast populations.

A two-level analysis of molecular variance (AMOVA) indicated that there was a highly significant divergence between individuals of different populations, with a recorded Φ_{ST} of 0.443. When the individuals from the 'northern' populations at Kremnos Creek and Newfoundland State Forest were excluded, Φ_{ST} was reduced to 0.297 but remained highly significant.

A three-level AMOVA was used to measure the percentage of molecular variance amongst regions, populations and within populations where the Kremnos Creek and Newfoundland populations were categorised as belonging to a 'northern' region, and the remaining populations to a 'southern' region. A value of Φ was calculated for each level; it was found that 65% of the variation lay within populations, 18% amongst regions and 17% amongst populations within regions (Table 2a).

A two way ANOVA on individuals from only the two 'northern' populations (Kremnos Creek and Newfoundland), showed 68% of the variation lay within populations and 32% amongst the populations (Table 2b). A two way ANOVA on individuals from the seven 'southern' populations (Somersby, Karuah, Calga, Nelsons Bay, Heathcote N.P., Lucas Heights and Darkes Forest) showed 82% of the variation lay within populations and 18% amongst the populations (Table 2c).

Discussion

RAPD markers showed measurable genetic differences within and between geographical populations of *Doryanthes excelsa.* A high degree of genetic differentiation was found between individuals of different populations, compared to individuals within populations. Overall, Φ_{ST} was 0.443, suggesting long isolation between populations. This value is higher than equivalent estimates for 'comparable' genera such as *Iris* and *Lilium*, when a comparison was made between Φ_{ST} and Nei's G_{ST} (Nei 1972) for related species. Arafeh *et al.* (2002) used RAPD data to calculate a G_{ST} of 0.21 for 242 individuals of *Iris atrofusca* and *Iris haynei* from Israel and Palestine indicating lower among-population differentiation than in *Doryanthes excelsa.* They also found greater within-population similarity in *Iris atrofusca*/*Iris haynei* than in *Doryanthes excelsa*, as is expected given that clonal reproduction in *Iris* is widespread, unlike *Doryanthes.*

In the UPGMA dendrogram, individuals outside the 'northern' populations (Kremnos Creek and Newfoundland) or Somersby (a 'southern' population) formed a loose cluster which suggests relative genetic similarity. These populations were in relatively close geographic proximity and so it may be expected that interpopulation diversity would be low relative to intrapopulation diversity. The proportion of molecular variance within the seven 'southern' populations (82% , Φ_{IS}=0.176) (Table 2c), supports the hypothesis that gene flow is relatively widespread between these populations as a whole.

The separation of the 'northern' populations (Kremnos Creek and Newfoundland) was likely due to a limitation in gene flow arising from geographical isolation. A distance of 330 km separates the northernmost Central Coast population of Nelsons Bay and the Newfoundland population. Since birds represent the most common vector for sticky pollen transfer in *Doryanthes*, one might expect minimal bird activity between these populations with gene flow reduced as a result,. According to Nash (1996) *Doryanthes excelsa* is pollinated by Cockatoos (*Cacatua galerita*) and Pied Currawongs (*Strepera graculina*) as well as smaller bird species that could carry pollen between the populations.

Whether or not recent gene flow has occurred between the 'northern' and 'southern' populations, the use of allele-specific markers would permit the measurement of allele type frequencies within each population. If such long-distance pollination occurred on even an occasional basis (an idea supported in part by the Φ_{ST} value and AMOVA calculations), allopatry could still be prevented. However the effectiveness of pollination of *Doryanthes excelsa* by large birds is limited because of the damage these species do to the flowers (Nash 1996).

The sampled individuals from Somersby also showed a relatively high degree of genetic differentiation, though unlike the 'northern' populations, Somersby was in close proximity to the other 'southern' populations. For instance, the Somersby and Calga populations were almost adjacent, separated by only 5 km across Brisbane Water National Park. The Calga site, substantially cleared and used for light agriculture for a considerable period has had greater agricultural development than the Somersby site, which was primarily composed of lightly cleared open forest with intermittent development.

The Calga plants were generally limited to a long, narrow tract of land between a farm fence and a road and it could be hypothesised that the Calga population is experiencing a bottleneck owing to a much-reduced population size and restricted gene flow due to the linear arrangement of surviving individuals. A bottleneck effect has been observed in other taxa, e.g. in Taiwan Wen and Hsiao (2001) found greater variation within high-altitude populations of *Lilium longiflorum* var. *formosanum* (Liliaceae) compared to the lower altitude populations, thought to be attributable to the diminished population size of the low-altitude populations as a result of agricultural expansion. In the predominantly outbreeding (Newman 1929) *Doryanthes excelsa*, there are generation times that could counteract bottlenecks and maintain intrapopulation diversity. Persson *et al.* (1998) found this to be the case for *Lilium martagon* (Liliaceae) growing in Europe.

The longevity of individual plants can ensure the preservation of alleles, even in small populations. *Doryanthes excelsa* may take up to 10 years from germination to flowering, and will live for decades. Most individuals will survive fires (the most common and dramatic disturbance event in their ecosystem) by resprouting after the forest has burnt (Denham & Auld 2002). The longevity of individuals means that the complete extinction of alleles within a population may be delayed for decades, and where there have been multiple selective events in succession, important alleles may be preserved throughout the period. However, commercial and/or illegal harvesting of inflorescences jeopardises this process and makes the population more vulnerable by reducing the capacity of individual plants to reproduce in any one season. The use of a co-dominant marker system in a further investigation of population diversity would shed further light on this issue. A phenotypic assessment would also be valuable to map any provenance types that may provide commercial opportunities for the cut-flower industry.

The results of this study suggest that there is lesser gene flow between the Kremnos Creek and Newfoundland populations, when compared to the 'southern' populations and that they have a significant level of genetic isolation. The two 'northern' populations should therefore be regarded as being of considerable value for both conservation authorities and the commercial breeding sector and should be given priority for conservation for both environmental and commercial reasons. The plants there appear to exhibit a smaller phenotype but confirming this requires further quantification.

By identifying the centres of molecular diversity, this study is an important first step towards developing *Doryanthes excelsa* as a horticultural resource. Through this process, this study provides an important basis upon which future conservation programs should be based, ensuring that wild populations remain in abundant numbers and that the Australian cut-flower industry can benefit from the development of this novel product.

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Post-fire recovery of woody plants in the New England Tableland Bioregion

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Abstract: The resprouting response of plant species to fire is a key life history trait that has profound effects on post-fire population dynamics and community composition. This study documents the post-fire response (resprouting and maturation times) of woody species in six contrasting formations in the New England Tableland Bioregion of eastern Australia. Rainforest had the highest proportion of resprouting woody taxa and rocky outcrops had the lowest. Surprisingly, no significant difference in the median maturation length was found among habitats, but the communities varied in the range of maturation times. Within these communities, seedlings of species killed by fire, mature faster than seedlings of species that resprout. The slowest maturing species were those that have canopy held seed banks and were killed by fire, and these were used as indicator species to examine fire immaturity risk. Finally, we examine whether current fire management immaturity thresholds appear to be appropriate for these communities and find they need to be amended.

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Introduction

Fire is a pervasive ecological factor that influences the evolution, distribution and abundance of woody plants (Whelan 1995; Bond & van Wilgen 1996; Bradstock et al. 2002). The resprouting response of plant species to fire is a key life history trait that has profound effects on post-fire population dynamics and community composition (Bellingham & Sparrow 2000, Bond & Midgley 2001). Hence, extensive efforts are being made to document the response of plants to fire in eastern Australia (e.g. Gill & Bradstock 1992; Benson & McDougall 1993, Clarke & Knox 2002, Walsh & McDougall 2004). Fire response classification systems have focused on whether a species is killed by fire or resprouts after fire, and whether seeds are stored in the canopy or in the soil (e.g. Gill & Bradstock 1992, Pausas et al. 2004). Whilst many factors such as fire season and intensity, plant physiological status and genetics can produce variable fire responses (e.g. Morrison & Renwick 2000, Wright & Clarke 2007) the response of species to a crown scorch fire can be useful in preliminary assessment of extirpation risks associated with fire regimes. Comparing the range of fire responses across habitats also informs models of ecological sorting and the potential for community shifts in response to changed fire regimes (e.g. Clarke & Knox 2002, Clarke et al. 2005, Pausas & Bradstock 2007).

Maturation times of new recruits for those plants killed by fire is also a critical biological variable in the context of fire regimes because this time sets the lower limit for fire intervals that can cause local population decline or extirpation (Keith 1996). Hence, fire intervals shorter than these maturation times pose an immaturity risk to populations of plants if they have no other means of persisting such as soil stored seed banks. These maturation times have been given the term ‘primary juvenile period’ (PJP) which refer to the time taken for seedlings to flower and produce viable seed. The primary juvenile period is particularly critical for those species that have a canopy stored seed bank because there is no mechanism, other than dispersal, by which populations can persist if the intervals between fires are shorter than the PJP (Gill & Bradstock 1992). For those plants that resprout the interval length between fires may seem to be of lesser importance; nevertheless, recruitment from seeds is required if long-term population decline is not to occur. In resprouting species both the PJP and the time taken for the resprouts to flower and produce fruits, secondary juvenile period, (SJP) is of consequence for maintenance of a seed supply.

The fire responses of shrubs on the New England Tablelands has been documented in grassy habitats by Knox and Clarke (2004), and the mesic forests by Campbell and Clarke (2006), whilst Clarke and Knox (2002) summarized the response of shrub species in four major formations. The aim of this

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study was to document the post-fire response (resprouting and maturation times) of woody species in six contrasting formations on the New England Tablelands in northern NSW. Firstly, we examined the resprouting ability of plants and whether the proportion of resprouters, variable and species killed by fire differed among habitats. Secondly, we examine the relationship between growth form and position of resprouting buds. Thirdly we examined maturation times and if there was a pattern of maturation time and resprouting ability. Finally, we discuss the implications of different fire regime intervals on plant populations and the role of management in ensuring population persistence in the face of changing fire regimes.

Methods

Study area

The study region is the New England Tableland (NET) Bioregion of eastern Australia with an altitudinal range of 750–1500 m (Thackway & Cresswell 1995). Six major vegetation formations that are prone to fire occur in the Bioregion; rainforest (RF) (Northern Warm Temperate Rainforest), wet sclerophyll forest (WSF) (Northern Escarpment Wet Sclerophyll Forests and Northern Escarpment Wet Sclerophyll Forest), dry sclerophyll forests (DSF) (New England Dry Scerophyll Forest, Northern Escarpment Dry Sclerophyll Forest and Northern Tableland Dry Sclerophyll Forest), grassy woodlands (GW) (Northern Grassy Woodlands), rocky outcrops heaths (RO) (Northern Montane Heaths) and wet heaths (WH) (Montane Bogs and Fens) (see Keith 2004). These broad groups form distinct floristic formations that are related to climate gradients, lithology and local physiography (Keith 2004). As a generalization, nutrient-poor siliceous soils provide habitats for scleromorphic shrub dominated woodlands and forests whilst the more fine-textured soils derived from metasediments and basalts support grassy woodlands and mesic forests (Benson & Ashby 2000). All habitats are prone to fires. Landscape scale fires in 2002 burnt into the more mesic wet sclerophyll forests and rainforests margins.

Field records

The fire response of woody species was recorded both quantitatively and qualitatively from direct observations of species in the post-fire environment for 489 taxa where their crowns had been burned. Repeated observations from independent fires were used to give a level of confidence in allocating species to fire response groups. In a few instances, fire response was inferred from root structures and comparing this with observations of closely related species. Post-fire observations were spread over several years using planned experimental, planned and unplanned fire from 1996 to 2008. Many species were observed in more than one or two formations. In these species the primary habitat in which they were recorded was used to allocate them to a habitat for trait analyses.

Growth forms, fire response groups, maturation and population status

The growth form of all woody species was determined from field observations, flora records and published records and summarized into seven groups corresponding to stem type and then height classes. The sprouting ability of at least five individuals (killed or resprouts) for at least two independent shrub populations were recorded where possible. Species could generally be classified into resprouters (70–100% of individuals in the population resprout) or obligate seeders (less than 30% of individuals resprout) (Gill & Bradstock 1992), although a third 'variable' resprouting class was also present (Clarke et al. 2005). In addition to data on resprouting, the position of resprouting and the type of seed bank was assessed for each species so they could be placed into one of the seven fire functional groups or syndromes of Gill and Bradstock (1992).

The minimum maturation times (time to seed set) of plants were observed from tagging seedling recruits in the post-fire environment or from observations of flowering and fruiting of species after fire. The mean time for primary juvenile period (PJP) and secondary juvenile period (SJP) was compared between growth form classes and resprouting class using a two factor ANOVA.

Vouchers and nomenclature

Identification of taxa was made in the field with verification against general field collections from the same reserve location in the NCW Beadle Herbarium (NE) at the University of New England. Less common species and taxa of uncertain status were also collected and lodged as vouchers in NE if flowering material was available. Several putative new taxa were also recorded and informal names have been allocated to these taxa. Nomenclature follows the latest printed version of the *Flora of New South Wales* (Harden 1990–3, 2002; Harden & Murray 2000) with the exception of those families that have recently changed names (Appendix 1) and where species names have changed (Appendix 2).

Results

Overview of regional coverage

Data on the fire response of 489 taxa were collected, of which 140 taxa had primary juvenile period (PJP) recorded and 105 taxa had secondary juvenile period (SJP) recorded (Appendix 3). Wet heath habitats had the lowest number of woody taxa fire responses (28) whilst the dry sclerophyll forest had the highest (170) (Table 1). Dry sclerophyll forest,

Table 1. Growth form classes showing the number of species observed after fire in each habitat, and the proportion (in brackets) resprouting. Variable species are grouped with the resprouting class. GW=Grassy woodland, DSF=Dry Sclerophyll Forest, RO=Rocky Outcrops, WH= Wet Heath, WSF=Wet Sclerophyll Forest, RF=Rainforest

Growth form				**Habitats**			
	GW	**DSF**	**RO**	**WH**	**WSF**	**RF**	**TOTAL**
Shrubs							
Sub-shrub (suffrutex)	5 (1)	9 (0.44)	0	4 (0.75)	0	0	18 (0.67)
Low shrub (<2m)	29 (0.69)	113 (0.60)	73 (0.19)	21 (0.81)	25 (0.72)	2 (1)	263 (0.53)
Tall shrub (>2m)	5 (0.60)	24 (0.58)	12 (0.33)	3 (1)	37 (0.54)	3 (1)	84 (0.56)
Climber							
Twiner (suffrutex)	2 (1)	6 (1)	0	0	4 (0.75)	0	12 (0.92)
Vine	0	0	0	0	7 (0.86)	13 (0.92)	20 (0.90)
Tree							
Small tree (< 10m)	3 (0.33)	9 (0.88)	3 (0)	0	16 (0.81)	23 (0.95)	54 (0.85)
Tree (> 10m)	1 (1)	9 (0.78)	0	0	7 (0.86)	21 (0.81)	38 (0.81)
All woody taxa	45 (0.73)	170 (0.63)	88 (0.21)	28 (0.82)	96 (0.65)	62 (0.90)	489 (0.62)

Table 2. Number of species in each habitat and resprouting class (Gill 1981)

Growth form				**Habitats**			
	GW	**DSF**	**RO**	**WH**	**WSF**	**RF**	**TOTAL**
Fire Response							
I. Killed, canopy-stored seed bank	0	3	3	1	1	0	8
II. Killed, soil-stored seed bank	9	54	62	4	24	4	157
III. Killed, no local seed bank	3	5	4	0	5	2	19
IV. Resprouts from root buds	2	4	1	0	8	5	20
V. Resprouts from basal buds	31	93	18	22	47	39	250
VI. Resprouts from stem buds	0	8	0	1	10	12	31
VI Resprouts from apical bud	0	3	0	0	1	0	4

grassy woodland, rocky outcrop and wet heath habitats have data records for almost all common shrub taxa recorded in these habitats. However, data on the wet sclerophyll forest and rainforest shrub taxa are less comprehensive as many more tree and shrubs occur in these habitats on the NE Tablelands (Table 1). In particular, the coverage of *Eucalyptus* is poor (19 species) because crown fires are rare in grassy and more mesic habitats.

Resprouting in habitats and growth forms

Across all taxa observed resprouting was present in 62% of the woody flora but differed among habitats, growth forms and growth forms within habitats (Table 1). Overall the proportion of species resprouting was highest in the rainforest (90%) followed by wet heath (82%), grassy woodlands (73%), wet sclerophyll forests (65%), dry sclerophyll forest (63%) and rocky outcrop (21%). Resprouting response was very high in climber species (>90%) whilst shrub species had the lowest (53%). Shrub sprouting capacity varied within habitats; 70% in wet heath and grassy woodland; 33% in rocky outcrops. Taller shrubs in the wet sclerophyll forests also tended to have less resprouting ability than lower shrubs (Table 1).

Fire response syndromes in habitats

The most common fire syndrome was resprouting from basal stem buds (51%), followed by species regenerating only from seed with soil stored seed banks (32%), and then those resprouting via stem buds (Table 2). Species that had canopy stored seed banks and were killed by fire (<2%) and those resprouting from only apical buds (<1%) were not common in any landscape. In some habitats there were very few or no species with certain fire response syndromes. This included the absence of species with canopy held seed banks that were killed by fire in grassy woodlands and rainforests (Table 2) and the low number of species with stem and apical resprouting in grassy woodlands, rocky outcrops and rainforests (Table 1).

Fire response syndromes in growth forms

Fire response syndromes were very unevenly distributed among growth forms with only the tall shrub class having all syndromes present (Table 3). Sub-shrubs only had two syndromes present amongst the 18 species in that class. As expected the tree class had a number of species resprouting from stem buds. The vine class also had a high proportion of species resprouting from nodes along fallen stems after fires.

Table 3. Number of species observed in each growth form class across standardised fire syndrome classes (Gill & Bradstock 1992)

Growth form	Habitats							
Fire Response	Sub-shrub	Low Shrub	Shrub	Twinner	Vine	Small Tree	Tree	TOTAL
I. Killed, canopy-stored seed bank	0	1	4	0	0	1	2	8
II. Killed, soil-stored seed bank	6	107	31	1	2	6	4	157
III. Killed, no local seed bank	0	15	2	0	0	1	1	19
IV. Resprouts from root buds	0	6	5	1	1	7	0	20
V. Resprouts from basal buds	12	133	36	10	6	36	17	250
VI. Resprouts from stem buds	0	0	3	0	11*	3	14	31
VI Resprouts from apical bud	0	1	3	0	0	0	0	4

* Stem nodes from fallen vines

Table 4. Minimum, mean (bold) and maximum maturation times in years for shrub taxa.

	Habitats						
Maturation	GW	DSF	RO	WH	WSF	RF	All
Primary juvenile period (PJP)	4–4.7–5	2–4.8–10	2–5.1–9	4–5.1–7	1–4.7–7	-	1–4.9–10
Secondary juvenile period (SJP)	1–2.9–5	2–2.7–5	3–3.3–5	1–2.4–4	1–2.6–5	-	1–2.9–6

Table 5. Proportion of resprouting taxa in woody plants sampled at plot scales (0.1 ha) and at landscape scales.
Data for plot scales from Clarke et al. 2005. The lower proportion of resprouting recorded at landscapes scales is due to the relative rarity of obligate seeders vs resprouters.

Landscape Scale	GW	DSF	RO	WH	WSF
0.1 ha plot mean	92	78	38	90	89
Landscape	73	63	21	82	65
Difference	19	15	17	8	24

Maturation times

We collected fewer data on maturation for PJP and SJP than resprouting syndromes, with fewer data on maturation times for species found in wet sclerophyll forests and rainforests (Table 4). Summary data for shrub species showed no significant difference in mean maturation times among habitats ($F_{4, 132} = 1.08$. $p > 0.1$), but a significant difference between mean maturation times for PJP vs SJP ($F_{1, 202} = 22.6$. $p < 0.001$). Over all habitats shrubs had a mean PJP maturation time of 4.9 years and mean SJP of 2.9 years; the range of SJP maturation times was greater (Table 4). The PJP differed between resprouters and obligate seeders ($F_{1, 128} = 9.7$. $p < 0.05$); 5.5 years compared to 4.8 years.

Field observations suggest rainfall influences PJP. In species with wide geographic ranges PJP was greater with lower annual rainfall e.g. the obligate seeder *Hakea macrorrhyncha* had a PJP of 4 years at Gibraltar Range (MAR >1400mm) whereas at Torrington its PJP was 7 years (MAR c. 800mm).

Discussion

Species and population variation in fire response

Overall, our data show how labile the resprouting trait is among the multiple lineages of the eudicot families, within genera and even within species. Within-species variation in the fire response may be due to the environment a plant occurs in or its genotype. Clear separation of these effects is not possible from field observations but genotypic inferences may be made where environmental constraints are thought to be similar. In general, most species in our study were readily assigned to either a resprouter or obligate seeder class with only a very small number of species exhibiting variation either within populations or between populations (see Appendix 3).

Gene based population differences in resprouting ability were suggested in several species (*Acacia venulosa, Correa* *reflexa, Dillwynia phylicoides, Dillwynia sieberi, Dodonaea viscosa, Eucalyptus oreades, Hardenbergia violacea, Kunzea bracteolata, Oxylobium arborescens*), whilst within population genetic variation was observed in *Hibbertia obtusifolia* and *Acacia ulicifolia*. In the case of *Hibbertia obtusifolia* an informally recognized species, (*H.* .sp. B) is killed by fire and is mainly restricted to rocky habitats whist *H. obtusifolia sensu stricto* is found in adjacent forest and strongly resprouts. Morphologically intermediate individuals are found in intermediate habitats and have mixed response to fire suggesting a strong genetic control. Variation in resprouting position was also detected between ecotypes of *Allocasuarina littoralis* with a form restricted to heaths resprouting from the base of stems whilst the forest form resprouted from stems. Differences were also recorded between populations of the forest tree *Eucalyptus oreades*. Following canopy fire populations on ridgetops resprouted (Gibraltar Range NP, Werrikimbi NP), while those in forest habitats (Carrai Plateau) were killed by fire.

Bioregional differences in resprouting ability are also apparent in our data, although many disparities may relate to poor taxonomic resolution of species. For example, a taxon known as *Epacris 'microphylla'* is recorded as being killed by fire in the Sydney Basin (SB) whereas it strongly resprouts throughout the NET Bioregion (NET). In this case there has been a long-standing misapplication of the name *E. 'microphylla'* in the NET Bioregion as this resprouting taxon is *E. gunnii*. In other cases closer examination of morphological and genetic difference may separate taxa that have contrasting resprouting abilities the two bioregions. Examples include *Acacia rubida* (SB resprout NET killed), *Bauera rubioides* (SB resprout NET killed), *Boronia ledifolia* (SB killed, NET resprouts), *Calytrix tetragona* (SB resprout NET killed), *Dillwynia sieberi* (SB killed NET resprouts), *Gompholobium latifolium* (SB resprout NET killed), *Goodia lotifolia* (SB killed NET resprouts), *Hibbertia acicularis* (SB killed NET resprouts), *Hibbertia linearis* (SB killed NET resprouts), *Kennedia rubicunda* (SB killed NET resprouts), *Olearia microphylla* SB killed NET resprouts), *Phyllota phylicoides* (SB killed NET resprouts), and *Sphaerolobium vimineum* (SB killed NET resprouts).We found examples where subspecies are known to have divergent traits, e.g. *Boronia anemonifolia* subsp. *variabilis* (NET killed), *Boronia anemonifolia* subsp. *anemonifolia* (SB resprouts), supporting the view that geographic differences are related to evolutionary divergence.

Landscape & community patterns of fire response

Whilst there is great variation in the ability to resprout among species, community patterns emerge when woody species are grouped into broad-scale vegetation types (Table 1, 2). The current study reinforces landscape patterns in woody species previously identified by Clarke & Knox 2002, Clarke et al. 2005, Campbell & Clarke 2006 where rocky outcrops and dry sclerophyll forest have the largest numbers of species killed by fire whereas those communities on more fertile soils have lower numbers of obligate seeding species.

Surprisingly, of the 62 rainforest taxa observed 90% were recorded as being resprouters, most of which have 'top kill' and resprout from basal buds as previously reported by Campbell and Clarke (2006). Of those tree species killed by fire many seem to be early successional species (*Dendrocnide, Polyscias*) but none show fire stimulated recruitment. Most rainforest vines resprouted from adventitious shoots at stem nodes when stems fall to the ground after fires. Adjacent, but more frequently burned, wet sclerophyll forests also had a high proportion of resprouting species present (65%) which is less than previously reported by Clarke et al. (2005) for the same region, but similar to that reported by Floyd in Ashton (1981) for *Eucalyptus pilularis* Wet Sclerophyll forest (WSF) forest. The difference is due to undersampling obligate seeding shrub species due to their patchy distribution. The obligate seeding species in WSF are mostly tall (2–3m) but relatively short-lived (< 20 yrs) shrubs that have fire stimulated recruitment; they include *Acacia irrorata, Asterolasia correifolia, Cassinia compacta, Correa lawrenciana* var. *glandulifera, Dodonaea megazyga, Hakea salicifolia, Logania albiflora, Olearia nernstii, Ozothamnus rufescens, Phebalium* Mt Ballow sp., *Persoonia media, Pimelea ligustrina* subsp. *hypericina, Prostanthera lasianthos, Pultenaea tarik, Solanum nobile,* and *Zieria arborescens*. Many of these species are also associated with rainforest margins which suggests that fire frequency influences their local distribution and abundance within the more mesic eucalypt forests.

Similar proportions of resprouting species (63%) also occur in the dry sclerophyll forests of the tablelands soils whilst grassy woodlands (73%) and the wet heaths (82%) supported much higher number of resprouting species. The rocky outcrops have low numbers of resprouters but very high numbers of obligate seeders; a pattern now well described in the literature (Clarke & Knox 2002, Clarke et al. 2005). In part, these landscape differences in fire response reflect the probability of crown fire return, but other factors such as site productivity and competitive interactions may also be important (Bellingham & Sparrow 2000, Clarke et al. 2005).

Invariably, the proportion of woody plants killed by crown fire measured at plot scales (< 1ha) (see Table 5) is lower than that recorded at landscape scales for the same Bioregion (Clarke et al. 2005). This is because obligate seeding species are more represented at the tail end of abundance frequency curves (see Clarke 2002). Hence, they are rarer in all landscapes and under-sampled in plots. Such scale effects suggest that fire regime exerts strong control on the localized presence of species in the landscape.

Maturation

Comprehensive data on maturation times for woody plants are critically important for the management of biodiversity because they reveal the immaturity risk posed by short fire intervals. Both within and among species variation in maturation times are driven by environmental and genotype factors which are not easily separated without manipulative or greenhouse experiments. One of the most striking examples of environmental control that has been observed in our region was the difference in the ability of an obligate seeding shrub (*Hakea macrorrhynca*) to flower and set fruits between populations of the same post-fire age at Torrington (MAR c. 800 mm) and those at Gibraltar Range (MAR > 1500 mm). After seven years of growth less than 5% of individuals had set fruit in the low rainfall site whilst at Gibraltar Range 99% of individuals had accumulated large numbers of fruits. Another example is the variation within populations of the obligate seeding shrub *Banksia marginata*. Plants at the margins of core habitats in forests had generally failed to accumulate seed banks after seven years post-fire but those at 'swamp' margins began to flower and set fruits within five years. Such population variation is under-estimated in our data because we record the shortest time to flowering and fruiting of an individual in populations, across all shrub species the minimum median maturation time for woody plants in the region was five years and ranged from one to 11 years which is broader than the range reported for the Sydney Basin (Benson 1985). Most data were collected from obligate seeding species and limited field observations suggest that the mean maturation rates of seedlings of resprouter species (5.5 yrs) is slower than obligate seeders (4.8 yrs). We found stronger evidence, however, that obligate seeders with a canopy held seed bank have longer PJP (6.2 yrs) than those that have soil-stored seed banks (4.7 yrs). Surprisingly we could not detect any habitat difference in maturation time although the range of PJP was wider in dry sclerophyll forests and rocky outcrop communities than other communities. Similarly, the secondary juvenile period in resprouters did not significantly vary among habitats but, on average, was much faster than the PJP.

Classification scheme and terminology

Classification schemes of the way species respond to fire are designed to help predict how populations and communities will respond to fire regimes (Whelan et al. 2002). Ideally this includes information on the 'vital attributes' of taxa which include dispersal, establishment and persistence such as that proposed by Noble and Slatyer (1980); however, such data are difficult to collect for comprehensive regional analyses. Instead, we use a simplified scheme that focuses on persistence ability (Gill 1981). The fire response scheme developed by Gill (1981) indicates whether taxa are killed by fire, and for those that resprout, where resprouting occurs. For those plants killed by fire it also indicates whether seed is held in canopy vs soil-stored seed banks but not where seeds are held in resprouting plants. It is not possible to identify from our data those species that only regenerate from sprouting, i.e. the so-called 'obligate resprouters'. Ascertaining obligate resprouting may be difficult because many environmental factors influence seed production, post-fire germination, and seedling emergence and survival. For example, several of the resprouting Ericacaceous species failed to establish seedlings in the first year post-fire but in the following years small numbers of seedlings were observed. We therefore think that whilst the term 'obligate resprouting' is appropriate, its application as a species trait needs careful long-term observation (see Clarke & Knox 2002). Overall, it appears that the number of species that lack any post-fire or fire interval recruitment from seeds is very low across the landscape and may only be restricted to a handful of species that are unable to set viable seed such as *Grevillea rhizomatosa* (Caddy & Gross 2006).

Application of Gill's resprouting scheme is sometimes problematic where taxa exhibit combinations of stem, basal and below ground resprouting. In particular many basal resprouting species also have resprouting from roots (e.g. *Acacia* spp.). Where this occurred we have used the lowest position of resprouting buds to allocate taxa to one of seven groups but in the appendix indicate that both forms of resprouting are possible. For global comparisons, the term 'top kill' is often used in savanna ecosystems to cover both those woody species that have basal and below ground resprouts although this term is rarely used in the sclerophyllous systems of eastern Australia.

The extent and intensity of recent fires on the escarpment of the Northern Tablelands of NSW allowed the categorization of many species in rainforests that would either be infrequently burned or where crowns of trees, shrubs and vines would rarely be burned. Categorization of rainforest shrubs and trees within the Gill scheme was simple where crowns had been burned, although for many larger rainforest trees it was difficult to find more than ten individuals where this had occurred. One group of plants that was difficult to assign to a Gill class were the vines (often lianas >2.5 cm dia) as they generally become detached from their support during fires and resprout from stems nodes where they have fallen after fires. These patterns are typical of vines as they vigorously resprout when they fall due to the production of adventitious roots and adventitious shoot buds (Fisher & Ewers 1991). Here we assign this resprouting capacity to 'stem' buds although most stems are situated on the ground and are also producing roots at stem nodes. Smaller vines, and scramblers, however, lack this capacity and generally resprout from basal stems or root tubers.

Conclusion – immaturity risk to plants from fire regimes

Our data highlight the range of fire responses to fire events across woody plants in the New England Tableland Bioregion and that communities differ in the composition of fire traits. Using these traits we can broadly assess the relative sensitivity of species and communities to projected fire frequencies that may be imposed through management or those that are likely without direct intervention. At the species level, a large number of taxa that are either listed or eligible for NSW State and/or Commonwealth under threatened species legislation and discussion of these threats will be covered elsewhere. More generally, across all community types, sequential fire intervals of less than five years are likely to cause local extirpations of fire killed species through adult deaths and exhaustion of either canopy or soil stored seed banks. Relatively large proportions (38%) of species fall into this obligate seeding group, although there are relatively few species of obligate seeding species with canopy held seed banks. Habitats that are particularly vulnerable to short fire intervals are rocky outcrops and the rainforest margins of wet sclerophyll forests with high concentrations of obligate seeders.

Table 6. Indicator species, primary juvenile period and minimum fire intervals that reduce immaturity risk for major vegetation classes in the New England Tableland Bioregion.
The current threshold recommendations of Kenny *et al.* (2004) are given. * 25 years recommended when *Callitris maclaeyana* is present otherwise 11 years.

Formation	Vegetation Classes (Keith 2004)	Indicator Species Gill Type I, II	Primary Juvenile Period (Years)	Immaturity Risk Threshold (years)	Current Thresholds
Wet Sclerophyll Forest	Northern Escarpment Wet Sclerophyll Forests	*Banksia integrifolia* subsp. *monticola*	8	11(25*)	25–60
		Hakea salicifolia	5		
		Persoonia media	6		
		Dodonaea megazyga	5		
		Callitris maclaeyana	25 (estimate)		
	Northern Tableland Wet Sclerophyll Forest	*Banksia integrifolia* subsp. *monticola*	8	11	10–50
		Hakea salicifolia	5		
		Persoonia media	5		
Dry Sclerophyll Forest	New England Dry Sclerophyll Forest	*Callitris oblonga*	8	11	5–50
		Banksia integrifolia var *monticola*	8		
		Leucopogon biflorus	5		
		Acacia rubida	4		
	Northern Escarpment Dry Sclerophyll Forest	*Allocasuarina rigida*	5	9	7–30
		Banksia marginata	5		
		Hibbertia rhynchocalyx	6		
		Grevillea acerata	4		
		Acacia terminalis	5		
	Northern Tableland Dry Sclerophyll Forest	*Callitris endlicheri*	7	11	7–30
		Styphelia triflora	7		
		Grevillea triternata	6		
		Acacia burbidgeae	8		
Grassy Woodland	Northern Grassy Woodlands	*Acacia dealbata*	5	8	5–40
		Cassinia leptocephala	5		
Rocky Outcrop	Northern Montane Heaths (Eastern)	*Callitris monticola*	9	12	7–30
		Hakea macrorrhyncha	5		
		Brachyloma saxicola	8		
		Boronia angustisepala	5		
	Northern Montane Heaths (western)	*Hakea macrorrhyncha*	8	12	7–30
		Kunzea bracteolata	6		
		Leionema rotundifolium	8		
		Homoranthus binghiensis	9		
		Acacia triptera	8		
Wet Heaths	Montane Bogs and Fens	*Banksia marginata*	4	8	6–35
		Bauera rubioides	5		
		Sprengelia incarnata	5		

Fire interval thresholds have been suggested for major vegetation formations in NSW based on species that are likely to be most at risk to short fire intervals (Kenny et al. 2004). Our finer scale analysis of vegetation types (Table 6) shows that the minimum interval to avoid immaturity risk to vulnerable species ranges from 8 to 11 years in fire prone formations in the New England Tableland Bioregion. These thresholds have been derived by determining the longest PJP for obligate seeding species that do not retain seed through a fire event (Gill's class I) and allowing three additional years for sufficient seed to accumulate (Keith et al. 2002). Our results indicate that minimum thresholds in the New England Tableland Bioregion need to be slightly more conservative in comparison to similar vegetation formations in other areas of NSW as many New England Tableland species take longer to reach maturity and therefore require a longer minimum fire interval.

Kenny et al. (2004) indicate a minimum threshold of 25 years for Wet Sclerophyll Forests because the most sensitive species in the analyses of Kenny et al. (2004) were obligate seeding *Eucalyptus* spp. In the Northern Escarpment Wet Sclerophyll Forests, obligate seeding eucalypts are absent, but the obligate seeder gymnosperm *Callitris maclaeyana* occurs uncommonly. Data are not available for the maturation time of *Callitris maclaeyana*. However, in cultivation no fruits have been produced by 21 year old planting (Floyd pers. comm.). Therefore, in areas in which *Callitris maclaeyana* occurs, a threshold of 25 years is suggested and in where this species is absent a threshold of 11 years is recommended. Clearly, these fire interval thresholds are a starting point to develop fire regimes models that incorporate season, intensity and the 'mosaic' concept as advocated by those concerned with all biodiversity components (Clarke 2008).

For those species that resprout, the consequences of repeated short interval fires are poorly known and rarely factored into species' risk assessment. Limited data on three commonly occurring resprouting shrubs shows that up to 15% of populations are killed by fire (Knox & Clarke 2006), hence seedling recruitment must occur to maintain current populations. Our study has predictably shown that seedlings of resprouters are slower to mature, but their ability to resprout prior to this maturation remains unknown. Similarly, whilst many rainforest shrubs and trees show 'tolerance' to a fire event, through vigorous resprouting, it is not known if recurrent fire causes mortality and recruitment failure. These topics are fertile ground for further research, not only in the NET Bioregion, but throughout fire prone south-eastern Australia.

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Appendix 1:

Recent changes to family placement of various genera compared with Flora of New South Wales (Harden 1990–3, 2002; Harden & Murray 2000)

Genus	New family placement used here as in APG III	Family as in *Flora of NSW*
Acrotriche	Ericaceae	Epacridaceae
Bauera	Cunoniaceae	Baueraceae
Brachychiton	Malvaceae	Sterculiaceae
Brachyloma	Ericaceae	Epacridaceae
Breynia	Phyllanthaceae	Euphorbiaceae
Chloanthes	Lamiaceae	Chloanthaceae
Commersonia	Malvaceae	Sterculiaceae
Doryphora	Atherospermataceae	Monimiaceae
Epacris	Ericaceae	Epacridaceae
Enstrephus	Asparagaceae	Luzuriagaceae
Geitonoplesium	Xanthorrhoeaceae	Luzuriagaceae
Keraudrenia	Malvaceae	Sterculiaceae
Lasiopetalum	Malvaceae	Sterculiaceae
Leucopogon	Ericaceae	Epacridaceae
Lissanthe	Ericaceae	Epacridaceae
Melichrus	Ericaceae	Epacridaceae
Monotoca	Ericaceae	Epacridaceae
Myoporum	Scrophulariaceae	Myoporaceae
Phyllanthus	Phyllanthaceae	Euphorbiaceae
Pseudanthus	Picrodendraceae	Euphorbiaceae
Sprengelia	Ericaceae	Epacridaceae
Styphelia	Ericaceae	Epacridaceae
Tetratheca	Elaeocarpaceae	Tremandraceae
Trema	Cannabaceae	Ulmaceae
Trochocarpa	Ericaceae	Epacridaceae
Tylophora	Apocynaceae	Asclepiadaceae

Appendix 2.

Nomenclatural changes to species names used in the *Flora of New South Wales* (Harden 1990–3, 2002; Harden & Murray 2000).

New name used here	Name in *Flora of NSW*
Akania paniculata	*Caldcluvia paniculosa*
Agiortia cicatricata	*Leucopogon cicatricatus*
Epacris gunnii	*Epacris microphylla*
Harmogia densifolia	*Babingtonia densifolia*
Kardonia odontocalyx	*Babingtonia odontocalyx*
Melaleuca linearis	*Callistemon linearis*
Melaleuca pallida	*Callistemon pallidus*
Melaleuca pityoides	*Callistemon pityoides*
Melaleuca williamsii	*Callistemon pungens*
Melaleuca paludicola	*Callistemon sieberi*
Myrsine howittiana	*Rapanea howittiana*
Myrsine variabilis	*Rapanea variabilis*
Philotheca epilosa	*Philotheca myoporoides* subsp. *epilosa*
Pittosporum multiflorum	*Citriobatus pauciflorus*
Homalanthus populifolius	*Omalanthus populifolius*
Pittosporum spinescens	*Citriobatus pauciflorus*
Spyridium scortechinii	*Cryptandra scortechinii*
Trema tomentosa var. *viridis*	*Trema aspera*

Appendix 3.

List of taxa and their habitats, fire response, primary juvenile period, secondary juvenile period and growth form.
Habitats – GW=Grassy woodland, DSF=Dry Sclerophyll Forest, RO=Rocky Outcrops, WH= Wet Heath, WSF=Wet Sclerophyll Forest, RF=Rainforest

Family	Species	Habitats	Gill	PJP	SJP	Growth Form
Anacardiaceae	*Euroschinus falcatus* var. *falcatus*	RF, WSF	VI			Tree
Apiaceae	*Platysace ericiodes*	DSF	V		2	Sub-shrub
Apiaceae	*Platysace lanceolata*	DSF	II	3	2	Sub-shrub
Apiaceae	*Xanthosia pilosa*	DSF	V		2	Sub-shrub
Apocynaceae	*Alyxia ruscifolia*	RF, WSF	V			Low shrub
Apocynaceae	*Marsdenia rostrata*	RF	VI			Vine
Apocynaceae	*Tylophora paniculata*	RF	VI			Vine
Araliaceae	*Astrotricha longifolia* s.l.	DSF	V		2	Low shrub
Araliaceae	*Astrotricha roddii*	RO	V			Low shrub
Araliaceae	*Cephalaralia cephalobotrys*	RF	VI			Vine
Araliaceae	*Polyscias elegans*	RF, WSF	II			Tree
Araliaceae	*Polyscias murrayi*	RF	V			Small tree
Araliaceae	*Polyscias sambucifolia* subsp. A (sens. Fl. NSW)	GW, DSF, WSF	IV		2	Tall shrub
Asteraceae	*Cassinia compacta*	WSF	II	5		Low shrub
Asteraceae	*Cassinia laevis*	GW	II			Low shrub
Asteraceae	*Cassinia lepschii*	DSF, RO	V		4	Low shrub
Asteraceae	*Cassinia leptocephala* subsp. *leptocephala*	GW	II	5		Low shrub
Asteraceae	*Cassinia quinquefaria*	DSF, GW	II		4	Low shrub
Asteraceae	*Cassinia straminea*	DSF	II			Low shrub
Asteraceae	*Cassinia telfordii*	WSF	II	5		Low shrub
Asteraceae	*Olearia alpicola*	WSF, DSF	V			Low shrub
Asteraceae	*Olearia covenyi*	WSF	V	6	3	Low shrub
Asteraceae	*Olearia cydoniifolia*	WSF, RF	V			Low shrub
Asteraceae	*Olearia gravis*	DSF	II	2		Low shrub
Asteraceae	*Olearia microphylla*	GW, DSF	V		3	Low shrub
Asteraceae	*Olearia myrsinoides*	DSF, GW	V		2	Low shrub
Asteraceae	*Olearia nernstii*	WSF	II	4		Low shrub
Asteraceae	*Olearia oppositifolia*	WSF, DSF, GW	V	7	3	Low shrub
Asteraceae	*Olearia phlogopappa*	DSF, WH	II			Low shrub
Asteraceae	*Olearia ramosissima*	GW, DSF	V			Low shrub
Asteraceae	*Olearia rosmarinifolia*	GW	V			Low shrub
Asteraceae	*Olearia* sp. aff. *elliptica*	DSF, GW	V			Low shrub
Asteraceae	*Olearia viscidula*	GW, DSF	V		2	Low shrub
Asteraceae	*Ozothamnus adnatus*	GW	II			Low shrub
Asteraceae	*Ozothamnus diosmifolius*	DSF, GW, WSF	IV			Low shrub
Asteraceae	*Ozothamnus diosmifolius*	RO, DSF	II	4		Low shrub
Asteraceae	*Ozothamnus obcordatus* (obligate seeding pops.)	RO	II			Low shrub
Asteraceae	*Ozothamnus obcordatus* (resprouting pops.)	GW	V			Low shrub
Asteraceae	*Ozothamnus rufescens*	WSF, RF	II	5		Low shrub
Asteraceae	*Ozothamnus* sp. 'Basket swamp'	WH	V	5		Low shrub
Atherospermataceae	*Doryphora sassafras*	RF, WSF	V			Tree
Berberidopsidaceae	*Berberidopsis beckleri*	RF	II			Vine
Bignoniaceae	*Pandorea pandorana*	RF, WSF	V			Vine
Cannabaceae	*Trema tomentosa* var. *viridis*	WSF	V			Tall shrub
Casuarinaceae	*Allocasuarina brachystachya*	WH, DSF	V	7		Tall shrub
Casuarinaceae	*Allocasuarina inophloia*	DSF	VI			Small tree
Casuarinaceae	*Allocasuarina littoralis*	WSF, DSF, GW	VI			Tall shrub
Casuarinaceae	*Allocasuarina littoralis* (Swamp form)	WH	V		3	Tall shrub
Casuarinaceae	*Allocasuarina rigida* subsp. *rigida*	RO, DSF	I	5		Tall shrub
Casuarinaceae	*Allocasuarina torulosa*	WSF, DSF	VI			Tree
Celastraceae	*Celastrus subspicatus*	RF	II			Tall shrub
Celastraceae	*Denhamia celastroides*	RF	V			Small tree
Celastraceae	*Maytenis bilocularis*	RF, WSF	V			Small tree
Celastraceae	*Maytenus silvestris*	WSF	V			Small tree

Family	Species	Habitats	Gill	PJP	SJP	Growth Form
Cunoniaceae	*Ackama paniculata*	RF	V			Tree
Cunoniaceae	*Bauera rubioides*	WH, DSF	II	6		Low shrub
Cunoniaceae	*Callicoma serratifolia*	RF, WSF	V		5	Tree
Cunoniaceae	*Ceratopetalum apetalum*	RF	V, VI			Tree
Cunoniaceae	*Schizomeria ovata*	RF	V, VII			Tree
Cupressaceae	*Callitris endlicheri*	DSF, RO	I	7		Tree
Cupressaceae	*Callitris monticola*	RO, DSF	I	9		Tall shrub
Cupressaceae	*Callitris oblonga* subsp. *parva*	DSF	I	8		Tall shrub
Dilleneaceae	*Hibbertia acicularis s.l.*	DSF, GW	V		3	Low shrub
Dilleneaceae	*Hibbertia aspera*	WSF, DSF	V			Low shrub
Dilleneaceae	*Hibbertia cistoidea*	DSF	V			Low shrub
Dilleneaceae	*Hibbertia dentata*	WSF	V, VI			Vine
Dilleneaceae	*Hibbertia empetrifolia*	WSF	V		1	Low shrub
Dilleneaceae	*Hibbertia linearis*	GW	V			Low shrub
Dilleneaceae	*Hibbertia obtusifolia s.l.*	DSF, GW, WSF	V		4	Low shrub
Dilleneaceae	*Hibbertia rhynchocalyx*	DSF, WSF	II	5		Low shrub
Dilleneaceae	*Hibbertia riparia* (Gibraltar Range form)	DSF	V			Low shrub
Dilleneaceae	*Hibbertia riparia* (Grassy woodlands form)	GW	V			Low shrub
Dilleneaceae	*Hibbertia riparia s.l.*	DSF, GW, WSF	V		2	Low shrub
Dilleneaceae	*Hibbertia scandens* var. *glabra*	WSF	VI		2	Vine
Dilleneaceae	*Hibbertia scandens* var. *scandens*	WSF	V		2	Vine
Dilleneaceae	*Hibbertia serpyllifolia*	DSF	V			Low shrub
Dilleneaceae	*Hibbertia* sp. aff. *obtusifolia*	DSF	II	6		Low shrub
Dilleneaceae	*Hibbertia* sp. aff. *rufa*	WH	V			Low shrub
Dilleneaceae	*Hibbertia* sp. B sens. Fl. Nsw	RO	II	8		Low shrub
Dilleneaceae	*Hibbertia vestita s.l.*	WH, WSF	V			Low shrub
Dilleneaceae	*Hibbertia villosa*	RO, DSF	II	5		Low shrub
Ebenaceae	*Diospyros australis*	RF	V			Small tree
Elaeocarpaceae	*Aristotelia australasica*	RF	V			Vine
Elaeocarpaceae	*Elaeocarpus reticulatus*	WSF, DSF	V			Small tree
Elaeocarpaceae	*Sloanea woollsii*	RF	II			Tree
Elaeocarpaceae	*Tetratheca thymifolia*	DSF	II	7		Low shrub
Ericaceae	*Acrotriche aggregata*	WSF, RF	V			Tall shrub
Ericaceae	*Agiortia cicatricata*	RO	II			Low shrub
Ericaceae	*Brachyloma daphnoides* subsp. *glabrum*	DSF, GW	V		3	Low shrub
Ericaceae	*Brachyloma saxicola*	RO	II	8		Low shrub
Ericaceae	*Epacris breviflora*	WH	V			Low shrub
Ericaceae	*Epacris longiflora*	DSF, WH	II	4		Low shrub
Ericaceae	*Epacris microphylla = gunnii*	DSF	V		2	Low shrub
Ericaceae	*Epacris obtusifolia*	WH	II	5		Low shrub
Ericaceae	*Leucopogon attenuatus*	DSF	V			Low shrub
Ericaceae	*Leucopogon biflorus*	RO, DSF	II	5		Low shrub
Ericaceae	*Leucopogon hookeri*	GW, DSF	V			Low shrub
Ericaceae	*Leucopogon lanceolatus* subsp. *lanceolatus*	WSF, DSF, GW	V	6	3	Tall shrub
Ericaceae	*Leucopogon melaleucoides*	DSF	V		2	Tall shrub
Ericaceae	*Leucopogon microphyllus* var. *pilibundus*	DSF, RO	II	4		Low shrub
Ericaceae	*Leucopogon muticus*	DSF, RO	II			Low shrub
Ericaceae	*Leucopogon neo-anglicus*	RO, DSF	II	5		Low shrub
Ericaceae	*Leucopogon* sp. aff. *apressus*	RO, DSF	II	4		Low shrub
Ericaceae	*Leucopogon* sp. aff. *fraseri*	GW, WSF	V			Low shrub
Ericaceae	*Leucopogon virgatus*	DSF	V			Low shrub
Ericaceae	*Lissanthe strigosa* subsp. *subulata*	GW, DSF	IV		2	Low shrub
Ericaceae	*Melichrus erubescens*	DSF	II			Low shrub
Ericaceae	*Melichrus procumbens*	DSF	V			Low shrub
Ericaceae	*Melichrus urceolatus*	DSF, GW	V		2	Low shrub
Ericaceae	*Monotoca scoparia*	DSF, GW, WSF	V	6	2	Tall shrub
Ericaceae	*Sprengelia incarnata*	WH	II	5		Low shrub
Ericaceae	*Styphelia perileuca*	RO, DSF	II			Low shrub

Family	**Species**	**Habitats**	**Gill**	**PJP**	**SJP**	**Growth Form**
Ericaceae	*Styphelia triflora*	DSF	II	7		Tall shrub
Ericaceae	*Trochocarpa laurina*	WSF	V			Small tree
Ericaceae	*Trochocarpa montana*	WSF, RF	V			Tall shrub
Escalloniaceae	*Anopteris macleayanus*	RF	V			Small tree
Euphorbiaceae	*Amperea xiphoclada* var. *xiphoclada*	DSF	V		2	Sub-shrub
Euphorbiaceae	*Claoxylon australe*	RF, WSF	V			Small tree
Euphorbiaceae	*Homalanthus nutans*	WSF	V			Low shrub
Euphorbiaceae	*Homalanthus populifolius*	RF, WSF	V			Tall shrub
Euphorbiaceae	*Ricinocarpus speciosus*	DSF	V			Tall shrub
Eupomatiaceae	*Eupomatia laurina*	RF, WSF	V			Tall shrub
Fabaceae-Faboideae	*Almaleea cambagei*	WH	V		3	Low shrub
Fabaceae-Faboideae	*Aotus ericiodes*	DSF	V		2	Low shrub
Fabaceae-Faboideae	*Aotus subglauca* var. *subglauca*	DSF	V	4	2	Low shrub
Fabaceae-Faboideae	*Bossiaea neo-anglica*	DSF, WSF	V		2	Low shrub
Fabaceae-Faboideae	*Bossiaea obcordata*	DSF	V			Low shrub
Fabaceae-Faboideae	*Bossiaea prostrata*	GW	V			Low shrub
Fabaceae-Faboideae	*Bossiaea rhombifolia* subsp. *rhombifolia*	DSF, RO	II			Low shrub
Fabaceae-Faboideae	*Bossiaea scortechinii*	DSF, GW, WSF	V	5		Low shrub
Fabaceae-Faboideae	*Davesia villifera*	DSF	II	3		Low shrub
Fabaceae-Faboideae	*Daviesia acicularis*	RO, DSF	II	2		Low shrub
Fabaceae-Faboideae	*Daviesia elliptica*	DSF, WSF	II			Tall shrub
Fabaceae-Faboideae	*Daviesia genistifolia*	GW	V			Low shrub
Fabaceae-Faboideae	*Daviesia latifolia*	GW, DSF, WSF	V	5		Tall shrub
Fabaceae-Faboideae	*Daviesia mimosoides* subsp. *mimosoides*	DSF	V			Tall shrub
Fabaceae-Faboideae	*Daviesia nova-anglica*	DSF	II	5		Low shrub
Fabaceae-Faboideae	*Daviesia ulicifolia* subsp. *ulicifolia*	GW, DSF	II			Low shrub
Fabaceae-Faboideae	*Daviesia umbellulata*	DSF	II	4		Low shrub
Fabaceae-Faboideae	*Desmodium rhytidophyllum*	GW, DSF	V			Twinner
Fabaceae-Faboideae	*Dillwynia phylicoides*	DSF	V			Low shrub
Fabaceae-Faboideae	*Dillwynia phylicoides*	DSF, RO	II	5		Low shrub
Fabaceae-Faboideae	*Dillwynia rupestris*	RO, DSF	II	5		Tall shrub
Fabaceae-Faboideae	*Dillwynia sericea*	DSF	II			Low shrub
Fabaceae-Faboideae	*Dillwynia sieberi*	GW	V		3	Low shrub
Fabaceae-Faboideae	*Dillwynia sieberi*	GW, DSF	II	5		Low shrub
Fabaceae-Faboideae	*Glycine clandestina*	DSF	V		2	Twinner
Fabaceae-Faboideae	*Gompholobium huegelii*	DSF	V		3	Low shrub
Fabaceae-Faboideae	*Gompholobium huegelii*	DSF	II			Sub-shrub
Fabaceae-Faboideae	*Gompholobium inconspicum*	DSF	II			Sub-shrub
Fabaceae-Faboideae	*Gompholobium latifolium*	DSF	II	3		Low shrub
Fabaceae-Faboideae	*Gompholobium uncinatum*	DSF	II	5		Sub-shrub
Fabaceae-Faboideae	*Gompholobium virgatum* var. *aspalathoides*	DSF	II			Low shrub
Fabaceae-Faboideae	*Goodia lotifolia* var. *lotifolia*	WSF	IV		4	Tall shrub
Fabaceae-Faboideae	*Hardenbergia violacea*	DSF, GW	V	5	3	Twinner
Fabaceae-Faboideae	*Hardenbergia violacea* (obligate seeder pop.)	WSF, DSF	II			Twinner
Fabaceae-Faboideae	*Hovea apiculata*	RO	II	4	3	Low shrub
Fabaceae-Faboideae	*Hovea graniticola*	RO	II	6		Low shrub
Fabaceae-Faboideae	*Hovea heterophylla*	GW, DSF	V		3	Sub-shrub
Fabaceae-Faboideae	*Hovea lanceolata*	RO, DSF	II	4		Low shrub
Fabaceae-Faboideae	*Hovea pedunculata*	RO, DSF	II	3		Low shrub
Fabaceae-Faboideae	*Indigofera adesmiifolia*	GW, DSF	V		5	Low shrub
Fabaceae-Faboideae	*Indigofera australis*	RO, DSF, WSF, GW	IV		4	Low shrub
Fabaceae-Faboideae	*Jacksonia scoparia*	GW, DSF, WSF	V	4	2	Tall shrub
Fabaceae-Faboideae	*Kennedia rubicunda*	DSF	V	3		Twinner
Fabaceae-Faboideae	*Lezpedeza juncea* subsp. *sericea*	GW	V		3	Sub-shrub
Fabaceae-Faboideae	*Mirbelia confertiflora*	RO	V		3	Tall shrub
Fabaceae-Faboideae	*Mirbelia pungens*	RO	II	2		Low shrub
Fabaceae-Faboideae	*Mirbelia rubiifolia*	DSF, RO	II	3		Low shrub
Fabaceae-Faboideae	*Mirbelia speciosa* subsp. *speciosa*	RO, DSF	II	6		Low shrub

Family	**Species**	**Habitats**	**Gill**	**PJP**	**SJP**	**Growth Form**
Fabaceae-Faboideae	*Oxylobium arbarescens* (Gibraltar Range form)	DSF	V		4	Low shrub
Fabaceae-Faboideae	*Oxylobium arborescens (Tall farm)*	RO, DSF	II			Tall shrub
Fabaceae-Faboideae	*Phyllota phylicoides*	DSF	V	4	3	Low shrub
Fabaceae-Faboideae	*Padolobium aestivum*	DSF	V		3	Low shrub
Fabaceae-Faboideae	*Padolobium ilicifolium*	DSF, GW, WSF	IV		2	Low shrub
Fabaceae-Faboideae	*Pultanaea tarik*	WSF, DSF	II	5		Tall shrub
Fabaceae-Faboideae	*Pultenaea campbellii*	GW	IV		3	Low shrub
Fabaceae-Faboideae	*Pultenaea daphnaides*	DSF	II			Low shrub
Fabaceae-Faboideae	*Pultenaea dentata*	WH	II			Sub-shrub
Fabaceae-Faboideae	*Pultenaea folialasa*	DSF	V	7	4	Low shrub
Fabaceae-Faboideae	*Pultenaea* sp. Girraween	WH	V			Low shrub
Fabaceae-Faboideae	*Pultenaea linophylla*	DSF, GW	II	3		Low shrub
Fabaceae-Faboideae	*Pultenaea micraphylla*	GW	V		3	Low shrub
Fabaceae-Faboideae	*Pultenaea polifalia*	DSF	II			Low shrub
Fabaceae-Faboideae	*Pultenaea pycnocephala*	DSF, RO	II	5		Low shrub
Fabaceae-Faboideae	*Pultenaea retusa*	DSF	II			Low shrub
Fabaceae-Faboideae	*Sphaerolobium vimineum*	WH	V		1	Sub-shrub
Fabaceae-Faboideae	*Zornia dyctiocarpa* var. *dyctiocarpa*	GW, DSF	V			Sub-shrub
Fabaceae-Mimosoideae	*Acacia adunca*	RO, DSF	II			Tall shrub
Fabaceae-Mimosoideae	*Acacia barringtonensis*	DSF	IV		3	Tall shrub
Fabaceae-Mimosoideae	*Acacia beadleana*	RO	V		3	Low shrub
Fabaceae-Mimosoideae	*Acacia betchei*	DSF	II			Tall shrub
Fabaceae-Mimosoideae	*Acacia binervata*	WSF	V			Tall shrub
Fabaceae-Mimosoideae	*Acacia blakei* subsp. *diphylla*	WSF	II			Small tree
Fabaceae-Mimosoideae	*Acacia brownii*	DSF	V			Low shrub
Fabaceae-Mimosoideae	*Acacia brunioides* subsp. *bruniaides*	DSF	II	4		Low shrub
Fabaceae-Mimosoideae	*Acacia burbidgeae*	DSF	II	8		Low shrub
Fabaceae-Mimosoideae	*Acacia buxifolia* subsp. *pubiflora*	DSF	V	5	2	Low shrub
Fabaceae-Mimosoideae	*Acacia dealbata*	WSF, DSF, GW	II	5		Small tree
Fabaceae-Mimosoideae	*Acacia diphylla*	RF	II			Tall shrub
Fabaceae-Mimosoideae	*Acacia falciformis*	RO, DSF, WSF, GW	IV		3	Tall shrub
Fabaceae-Mimosoideae	*Acacia filicifolia*	WSF, DSF	IV	5	5	Small tree
Fabaceae-Mimosoideae	*Acacia fimbriata*	GW, DSF	II	4		Small tree
Fabaceae-Mimosoideae	*Acacia flaribunda*	WSF	V			Tall shrub
Fabaceae-Mimosoideae	*Acacia granitica*	RO	II	5		Tall shrub
Fabaceae-Mimosoideae	*Acacia gunnii*	DSF, GW	V			Low shrub
Fabaceae-Mimosoideae	*Acacia hispidula*	RO, DSF	II			Low shrub
Fabaceae-Mimosoideae	*Acacia implexa*	DSF, GW	IV		5	Tall shrub
Fabaceae-Mimosoideae	*Acacia irrorata* subsp. *irrorata*	WSF	II			Small tree
Fabaceae-Mimosoideae	*Acacia juncifolia* subsp. *juncifalia*	DSF	V			Small tree
Fabaceae-Mimosoideae	*Acacia latisepala*	RO	II	6		Tall shrub
Fabaceae-Mimosoideae	*Acacia leptoclada*	DSF	V			Low shrub
Fabaceae-Mimosoideae	*Acacia longifolia* subsp. *langifolia*	DSF, WSF	II	6		Tall shrub
Fabaceae-Mimosoideae	*Acacia macnuttiana*	DSF	II			Tall shrub
Fabaceae-Mimosoideae	*Acacia maidenii*	RF, WSF	V			Small tree
Fabaceae-Mimosoideae	*Acacia melanoxylon*	RF, WSF	IV			Small tree
Fabaceae-Mimosoideae	*Acacia mitchellii*	DSF	II	5		Low shrub
Fabaceae-Mimosoideae	*Acacia myrtifalia*	DSF, WSF	II	4		Low shrub
Fabaceae-Mimosoideae	*Acacia neriifolia*	RO, DSF, GW	IV			Small tree
Fabaceae-Mimosoideae	*Acacia nova-anglica* ms	RO, DSF, WSF, GW	IV		4	Small tree
Fabaceae-Mimosoideae	*Acacia abtusifolia*	DSF, WSF	V	4		Low shrub
Fabaceae-Mimosoideae	*Acacia penninervis* var. *penninervis*	DSF	II			Tall shrub
Fabaceae-Mimosoideae	*Acacia pruinasn*	DSF	V			Tall shrub
Fabaceae-Mimosoideae	*Acacia pycnastachya*	RO, DSF	V			Small tree
Fabaceae-Mimosoideae	*Acacia rubida*	DSF	II	4		Tall shrub
Fabaceae-Mimosoideae	*Acacia suaveolens*	DSF	II	3		Low shrub
Fabaceae-Mimosoideae	*Acacia terminalis*	DSF	II	5		Tall shrub
Fabaceae-Mimosoideae	*Acacia tarringtanensis*	RO, DSF	II	4		Low shrub

Family	Species	Habitats	Gill	PJP	SJP	Growth Form
Fabaceae-Mimosoideae	*Acacia triptera*	RO, DSF	II	8		Tall shrub
Fabaceae-Mimosoideae	*Acacia ulicifolia*	RO, DSF, GW, WSF	II	3		Low shrub
Fabaceae-Mimosoideae	*Acacia venulosa*	DSF	V			Low shrub
Fabaceae-Mimosoideae	*Acacia venulosa* (obligate seeding pop.)	RO, DSF	II	5		Low shrub
Fabaceae-Mimosoideae	*Acacia viscidula*	GW	V			Low shrub
Fabaceae-Mimosoideae	*Acacia viscidula*	RO, DSF	II			Low shrub
Fabaceae-Mimosoideae	*Acacia williamsiana*	RO	IV			Small tree
Goodeniaceae	*Goodenia ovata*	WSF	II		2	Low shrub
Xanthorrhoeaceae	*Gietonoplesium cymosum*	WSF	IV			Twinner
Lamiaceae	*Chloanthes parviflora*	RO	II			Low shrub
Lamiaceae	*Prostanthera incisa*	WSF	II			Tall shrub
Lamiaceae	*Prostanthera lasianthos*	WSF	II			Tall shrub
Lamiaceae	*Prostanthera nivea*	RO	II	3		Low shrub
Lamiaceae	*Prostanthera nivea* var. *nivea*	RO	II	3		Low shrub
Lamiaceae	*Prostanthera 'ovalifolia'*	WSF	II			Tall shrub
Lamiaceae	*Prostanthera saxicola*	RO	II	3		Low shrub
Lamiaceae	*Prostanthera scutellarioides* (Carrai form)	WH	V		1	Low shrub
Lamiaceae	*Prostanthera scutellarioides* (Gibraltar Range form)	DSF	V		3	Low shrub
Lamiaceae	*Prostanthera* sp. aff. *howelliae*	DSF	V		4	Low shrub
Lamiaceae	*Prostanthera teretifolia*	RO	II	8		Low shrub
Lamiaceae	*Westringia amabilis*	DSF	II	4		Low shrub
Lamiaceae	*Westringia eremicola*	DSF	V			Low shrub
Lauraceae	*Cinnamomum oliveri*	RF, WSF	V			Tree
Lauraceae	*Cryptocarya foveolata*	RF, WSF	V			Small tree
Lauraceae	*Cryptocarya glaucescens*	RF, WSF	V			Small tree
Lauraceae	*Cryptocarya meisneriana*	RF, WSF	V			Small tree
Lauraceae	*Cryptocarya rigida*	RF, WSF	V		6	Small tree
Lauraceae	*Endiandra muelleri*	RF, WSF	V			Tree
Lauraceae	*Endiandra sieberi*	RF, WSF	V			Tree
Lauraceae	*Litsea reticulata*	RF	II			Tree
Asparagaceae	*Eustrephus latifolius*	WSF	IV			Vine
Loganiaceae	*Logania albiflora*	WSF	II	5		Tall shrub
Loganiaceae	*Logania* sp. aff. *albiflora* (narrow leaves, rocky habitat)	DSF	V			Low shrub
Malvaceae	*Brachychiton populneus* subsp. *populneus*	GW	V			Tree
Malvaceae	*Commersonia amystia*	RO	II	3		Low shrub
Malvaceae	*Commersonia breviseta*	RO	II	4		Low shrub
Malvaceae	*Keraudrenia hillii* var. *hillii*	RO	II	5		Low shrub
Malvaceae	*Lasiopetalum macrophyllum*	WSF	V			Low shrub
Meliaceae	*Dysoxylum fraserianum*	RF	V			Tree
Meliaceae	*Synoum glandulosum*	WSF, RF	V			Low shrub
Menispermaceae	*Sarcopetalum harveyanum*	WSF, RF	V			Twinner
Monimiaceae	*Hedycarya angustifolia*	WSF, RF	V		6	Small tree
Monimiaceae	*Palmeria scandens*	RF	VI			Vine
Monimiaceae	*Wilkiea heugeliana*	RF	V			Small tree
Myrsinaceae	*Myrsine howittiana*	WSF	V			Small tree
Myrsinaceae	*Myrsine variabilis*	WSF	V			Small tree
Myrtaceae	*Acmena smithii*	RF, WSF	VI			Tree
Myrtaceae	*Archirhodomyrtus beckleri*	RF, WSF	V		6	Small tree
Myrtaceae	*Baeckea omissa*	WH	V	4	1	Low shrub
Myrtaceae	*Calytrix tetragona*	RO	II	6		Low shrub
Myrtaceae	*Eucalyptus acaciiformis*	DSF	V			Small tree
Myrtaceae	*Eucalyptus brunnea*	DSF	VI			Tree
Myrtaceae	*Eucalyptus caliginosa*	DSF	VI			Tree
Myrtaceae	*Eucalyptus cameronii*	WSF	VI			Tree
Myrtaceae	*Eucalyptus campanulata*	WSF	VI			Tree
Myrtaceae	*Eucalyptus codonocarpa*	RO	V		5	Tall shrub
Myrtaceae	*Eucalyptus laevopinea*	DSF	VI			Tree
Myrtaceae	*Eucalyptus ligustrina*	DSF	VI			Small tree

Family	Species	Habitats	Gill	PJP	SJP	Growth Form
Myrtaceae	*Eucalyptus microcorys*	WSF	VI			Tree
Myrtaceae	*Eucalyptus nobilis*	WSF	II			Tree
Myrtaceae	*Eucalyptus notabilis*	WSF, DSF	VI			Tree
Myrtaceae	*Eucalyptus obliqua*	WSF, DSF	VI			Tree
Myrtaceae	*Eucalyptus olida*	DSF	V			Small tree
Myrtaceae	*Eucalyptus oreades*	DSF	I			Tree
Myrtaceae	*Eucalyptus prava*	RO	V		5	Small tree
Myrtaceae	*Eucalyptus pyrocarpa*	DSF	VI			Tree
Myrtaceae	*Eucalyptus radiata* subsp. *sejuncta*	DSF	VI			Tree
Myrtaceae	*Eucalyptus saligna*	WSF	VI			Tree
Myrtaceae	*Eucalyptus williamsiana*	DSF	VI			Tree
Myrtaceae	*Harmogia densifolia*	RO	V			Low shrub
Myrtaceae	*Homoranthus biflorus*	RO	II			Low shrub
Myrtaceae	*Homoranthus binghiensis*	RO	II	9		Low shrub
Myrtaceae	*Homoranthus croftianus*	RO	II			Low shrub
Myrtaceae	*Homoranthus lunatus*	RO	II			Low shrub
Myrtaceae	*Kardomia odontocalyx*	RO	II	8		Low shrub
Myrtaceae	*Kunzea bracteolata* (obligate seeder pop.)	RO	I	6		Low shrub
Myrtaceae	*Kunzea bracteolata* (resprouter pop.)	RO	V			Low shrub
Myrtaceae	*Kunzea obovata*	RO	II			Low shrub
Myrtaceae	*Kunzea opposita*	RO	I			Low shrub
Myrtaceae	*Kunzea parvifolia*	DSF, GW	II			Low shrub
Myrtaceae	*Leptospermum arachnoides*	WH	V		3	Low shrub
Myrtaceae	*Leptospermum brevipes*	RO, DSF, GW	V		3	Tall shrub
Myrtaceae	*Leptospermum divaricatum*	RO, DSF	V			Low shrub
Myrtaceae	*Leptospermum gregarium*	WH	V		3	Low shrub
Myrtaceae	*Leptospermum minutifolium*	WH	V		3	Low shrub
Myrtaceae	*Leptospermum novae-angliae*	RO, DSF	V	8	3	Low shrub
Myrtaceae	*Leptospermum petersonii*	RO, DSF	V			Tall shrub
Myrtaceae	*Leptospermum polygalifolium* subsp. *montanum*	WSF	V		2	Tall shrub
Myrtaceae	*Leptospermum polygalifolium* subsp. *transmontanum*	DSF, WSF	V		2	Tall shrub
Myrtaceae	*Leptospermum trinervium*	DSF	VI		2	Tall shrub
Myrtaceae	*Lophostemon confertus*	RF, WSF	VI			Tree
Myrtaceae	*Melaleuca linearis*	DSF	V			Low shrub
Myrtaceae	*Melaleuca pallida*	WH	V			Tall shrub
Myrtaceae	*Melaleuca paludicola*	WH	V		4	Low shrub
Myrtaceae	*Melaleuca pityoides*	WH	V			Low shrub
Myrtaceae	*Melaleuca sp nov./comboynensis*	RO	V			Low shrub
Myrtaceae	*Melaleuca* sp. aff. *comboynensis* ('Big Red')	RO	V		3	Low shrub
Myrtaceae	*Melaleuca* sp. aff. *flavovirens* (Torrington)	DSF	V	10		Low shrub
Myrtaceae	*Melaleuca williamsii*	DSF	V			Low shrub
Myrtaceae	*Micromyrtus sessilis*	RO, DSF	V			Low shrub
Myrtaceae	*Rhodamnia rubescens*	RF, WSF	IV			Small tree
Olacaceae	*Olax stricta*	DSF, RO	V			Tall shrub
Oleaceae	*Notelaea linearis*	WSF, RF	V			Tall shrub
Oleaceae	*Notelaea microcarpa* var. *microcrpa*	WSF, DSF, GW	V			Tall shrub
Oleaceae	*Notelaea* sp. A	WSF, DSF	V			Tall shrub
Oleaceae	*Notelaea venosa*	WSF, RF	V			Small tree
Phyllanthaceae	*Breynia oblongifolia*	WSF	V			Low shrub
Phyllanthaceae	*Phyllanthus gunnii*	WSF	V			Low shrub
Phyllanthaceae	*Phyllanthus subcrenulatus*	GW	V			Sub-shrub
Phyllanthaceae	*Phyllanthus virgatus*	DSF	V			Sub-shrub
Phyllanthaceae	*Synostemon hirtellus*	DSF	II	5		Low shrub
Picrodendraceae	*Pseudanthus pauciflorus*	RO	II	4		Low shrub
Pittosporaceae	*Billardiera scandens*	DSF, WSF, GW	V			Twinner
Pittosporaceae	*Bursaria spinosa* subsp. *spinosa*	GW	V		5	Tall shrub
Pittosporaceae	*Hymenosporum flavum*	RF, WSF	V			Small tree
Pittosporaceae	*Pittosporum multiflorum*	RF, WSF	IV			Small tree

Family	Species	Habitats	Gill	PJP	SJP	Growth Form
Pittosporaceae	*Pittosporum revolutum*	RF, WSF	V			Small tree
Pittosporaceae	*Pittosporum spinescens*	RF, WSF	IV			Low shrub
Pittosporaceae	*Pittosporum undulatum*	RF, WSF	V			Small tree
Pittosporaceae	*Rhytidosporum diosmoides*	DSF, GW	V		3	Twinner
Pittosporaceae	*Rhytidosporum procumbens*	GW	V	5	3	Twinner
Polygalaceae	*Comesperma defoliatum*	WH	V			Sub-shrub
Polygalaceae	*Comesperma ericinum*	DSF, RO	II	2		Low shrub
Polygalaceae	*Comesperma retusum*	WH	V			Sub-shrub
Escalloniaceae	*Polyosma cunninghamii*	RF	V			Small tree
Proteaceae	*Banksia integrifolia* subsp. *monticola*	WSF, DSF, GW	I	8		Small tree
Proteaceae	*Banksia marginata*	WH	I	4		Low shrub
Proteaceae	*Banksia spinulosa* subsp. *collina*	DSF	V			Low shrub
Proteaceae	*Banksia spinulosa subsp. neoanglica*	DSF, WH	V	6	2	Tall shrub
Proteaceae	*Conospermum burgessiorium*	DSF	II	5		Low shrub
Proteaceae	*Conospermum taxifolium*	DSF, WH	V		4	Low shrub
Proteaceae	*Grevillea acanthifolia* subsp. *stenomera*	WH	V		4	Low shrub
Proteaceae	*Grevillea acerata*	DSF	II	4		Low shrub
Proteaceae	*Grevillea beadleana*	RO	II			Low shrub
Proteaceae	*Grevillea floribunda* subsp. *floribunda*	DSF	V			Low shrub
Proteaceae	*Grevillea guthrienana*	RO	II			Low shrub
Proteaceae	*Grevillea juniperina* subsp. *allojohnsonii*	GW, DSF	V			Low shrub
Proteaceae	*Grevillea rhizomatosa*	WSF, DSF	IV		5	Low shrub
Proteaceae	*Grevillea scotechenii* subsp. *sarmentosa*	DSF	V			Low shrub
Proteaceae	*Grevillea triternata*	DSF, RO	II	6		Low shrub
Proteaceae	*Grevillea viridiflava*	DSF, WH	V		4	Low shrub
Proteaceae	*Hakea eriantha*	WSF, DSF, GW	V	5		Tall shrub
Proteaceae	*Hakea laevipes* subsp. *graniticola*	DSF	V	5	3	Low shrub
Proteaceae	*Hakea macrorrhyncha*	RO	I	5		Small tree
Proteaceae	*Hakea microcarpa*	WH	V	5	2	Low shrub
Proteaceae	*Hakea salicifolia* subsp. *salicifolia*	WSF	I	5		Tall shrub
Proteaceae	*Isopogon petiolaris*	DSF	V	4	4	Low shrub
Proteaceae	*Lomatia arborescens*	WSF	V			Small tree
Proteaceae	*Lomatia fraseri*	DSF, WSF	V			Low shrub
Proteaceae	*Lomatia silaifolia*	WSF, DSF, GW	V		1	Low shrub
Proteaceae	*Orites excelsa*	RF, WSF	II			Small tree
Proteaceae	*Persoonia acuminata*	WSF	V			Low shrub
Proteaceae	*Persoonia chamaepeuce*	DSF	V		4	Low shrub
Proteaceae	*Persoonia conjuncta*	WSF	II			Tall shrub
Proteaceae	*Persoonia cornifolia*	DSF	V			Tall shrub
Proteaceae	*Persoonia fastigiata*	DSF	V			Low shrub
Proteaceae	*Persoonia linearis*	WSF	VI			Tall shrub
Proteaceae	*Persoonia media*	WSF, RF	II	6		Small tree
Proteaceae	*Persoonia oleoides*	WSF, DSF	V			Tall shrub
Proteaceae	*Persoonia procumbens*	DSF	V			Low shrub
Proteaceae	*Persoonia rufa*	DSF, RO	II	6		Low shrub
Proteaceae	*Persoonia sericea*	DSF, WSF	V			Low shrub
Proteaceae	*Persoonia tenuifolia*	DSF	V		4	Low shrub
Proteaceae	*Persoonia terminalis* subsp. *terminalis*	RO	II			Low shrub
Proteaceae	*Petrophile canescens*	DSF	V		3	Low shrub
Proteaceae	*Stenocarpus salignus*	RF	V			Small tree
Proteaceae	*Telopea aspera*	DSF	V		2	Low shrub
Quintiniaceae	*Quintinia seiberi*	RF	V, VI			Tree
Ranunculaceae	*Clematis aristata*	WSF, RF	V			Vine
Ranunculaceae	*Clematis glycinoides*	WSF, RF	II			Vine
Rhamnaceae	*Cryptandra amara* var. *floribunda*	RO	II	3		Low shrub
Rhamnaceae	*Cryptandra amara* var. *longfolia*	GW	V		3	Low shrub
Rhamnaceae	*Pomaderiris* (long Point small leaf)	GW, DSF	II			Tall shrub
Rhamnaceae	*Pomaderris andromedifolia*	RO	II			Low shrub

Family	Species	Habitats	Gill	PJP	SJP	Growth Form
Rhamnaceae	*Pomaderris angustifolia*	DSF	II			Low shrub
Rhamnaceae	*Pomaderris betulina*	DSF	II			Low shrub
Rhamnaceae	*Pomaderris eriocephala*	GW	V			Low shrub
Rhamnaceae	*Pomaderris lanigera*	DSF, WSF	II			Low shrub
Rhamnaceae	*Pomaderris nitidula*	WSF, RF	II			Low shrub
Rhamnaceae	*Pomaderris prunifolia*	GW	II			Low shrub
Rhamnaceae	*Spyridium scortechinii*	RO, DSF	II	4		Low shrub
Ripogoneaceae	*Ripogonum discolor*	RF	VI			Vine
Rosaceae	*Rubus moluccanus*	RF, WSF	VI			Vine
Rosaceae	*Rubus mooreii*	RF	VI			Vine
Rosaceae	*Rubus parvifolius*	WSF, DSF	V			Twinner
Rubiacae	*Psychotria loniceroides*	WSF, RF	V			Small tree
Rubiaceae	*Coprosma hirtella*	WSF	V			Low shrub
Rubiaceae	*Coprosma quadrifida*	WSF	V			Small tree
Rubiaceae	*Psychotria loniceroides*	WSF, RF	V			Small tree
Rutaceae	*Acronychia oblongifolia*	RF	V			Tree
Rutaceae	*Asterolasia asteroscophora* subsp. *asteroscophora*	DSF	II	4		Low shrub
Rutaceae	*Asterolasia correifolia*	WSF	II	4		Tall shrub
Rutaceae	*Boronia algida*	DSF	V		2	Low shrub
Rutaceae	*Boronia anemonifolia* subsp. *variablis*	RO	II			Low shrub
Rutaceae	*Boronia anethifolia*	RO	II	3		Low shrub
Rutaceae	*Boronia angustisepala*	RO, DSF	II	5		Low shrub
Rutaceae	*Boronia bolivensis*	RO	II	5		Low shrub
Rutaceae	*Boronia granitica*	RO	II	6		Low shrub
Rutaceae	*Boronia ledifolia*	DSF	V		2	Low shrub
Rutaceae	*Boronia microphylla*	DSF, WH	V		2	Low shrub
Rutaceae	*Boronia polygalifolia*	WH, DSF, GW	V		1	Low shrub
Rutaceae	*Correa lawrenciana* var. *glandulifera*	WSF	II	5		Tall shrub
Rutaceae	*Correa reflexa* (resprouter green flowered)	GW	V			Low shrub
Rutaceae	*Correa reflexa* (obligate seeder red flowered)	DSF	II	5		Low shrub
Rutaceae	*Crowea exaltata* subsp. *magnifolia*	DSF, RO	II			Low shrub
Rutaceae	*Eriostemon australasius* subsp. *australasius*	RO	II	5		Low shrub
Rutaceae	*Leionema ambiens*	RO	II			Low shrub
Rutaceae	*Leionema dentatum*	RO	II	5		Low shrub
Rutaceae	*Leionema rotundifolium*	RO	II	8		Low shrub
Rutaceae	*Leionema rotundifolium*	RO, DSF	V			Low shrub
Rutaceae	*Medicosma cunninghamii*	RF, WSF	V			Tree
Rutaceae	*Melicope hayesii*	RF, WSF	V			Tree
Rutaceae	*Melicope micrococca*	RF, WSF	V			Tree
Rutaceae	*Phebalium glandulosum* subsp. *eglandulosum*	RO	II	8		Low shrub
Rutaceae	*Phebalium squamulosum* subsp. *squamulosum*	RO, DSF	II	5		Low shrub
Rutaceae	*Phebalium* sp. Mt Ballow	WSF	II			Tall shrub
Rutaceae	*Phebalium woombye*	RO	II	5		Low shrub
Rutaceae	*Philotheca epilosa*	RO	II	7		Low shrub
Rutaceae	*Zieria arborescens*	WSF	II			Tall shrub
Rutaceae	*Zieria aspalathoides*	RO, DSF	II	4		Low shrub
Rutaceae	*Zieria cytisoides*	RO, DSF	V			Low shrub
Rutaceae	*Zieria laevigata*	RO	II	3		Low shrub
Rutaceae	*Zieria odorifera*	RO	V			Low shrub
Rutaceae	*Zieria smithii* subsp. *smithii*	WSF	II	5		Tall shrub
Santalaceae	*Choretrum candollei*	DSF	V			Low shrub
Santalaceae	*Choretrum pauciflorum*	RO	II			Low shrub
Santalaceae	*Exocarpos cupressiformis*	GW, WSF	V			Small tree
Santalaceae	*Exocarpos strictus*	DSF	V			Small tree
Santalaceae	*Leptomeria acida*	DSF	II			Tall shrub
Sapindaceae	*Dodonaea boroniifolia*	DSF, RO	II			Low shrub
Sapindaceae	*Dodonaea hirsuta*	RO	II	6		Low shrub
Sapindaceae	*Dodonaea megazyga*	WSF	II	5		Tall shrub

Family	**Species**	**Habitats**	Gill	PJP	SJP	**Growth Form**
Sapindaceae	*Dodonaea triquetra*	GW, DSF, WSF	V			Low shrub
Sapindaceae	*Dodonaea viscosa* subsp. Black Fruits	DSF, GW	V			Low shrub
Sapindaceae	*Dodonaea viscosa* subsp. *spatulata*	DSF, RO	II			Low shrub
Scrophulariaceae	*Myoporum betcheanum*	RF	II			Tall shrub
Smilacaceae	*Smilax australis*	WSF, RF	V			Vine
Smilacaceae	*Smilax glyciphylla*	DSF, WSF	V			Twinner
Solanaceae	*Duboisia myoporoides*	RF	V			Small tree
Solanaceae	*Solanum aviculare*	WSF, RF	II	1		Tall shrub
Solanaceae	*Solanum curvicuspe*	WSF, RF	V		2	Tall shrub
Solanaceae	*Solanum densevestitum*	WSF	V			Low shrub
Solanaceae	*Solanum nobile*	WSF, RF	II	3		Tall shrub
Solanaceae	*Solanum prinophyllum*	WSF, RF	II	3		Low shrub
Thymelaeaceae	*Pimelea curviflora* var. *divergens*	GW	V		1	Sub-shrub
Thymelaeaceae	*Pimelea ligustrina* subsp. *hypericina*	WSF	II	5		Tall shrub
Thymelaeaceae	*Pimelea linifolia* subsp. *collina*	DSF, RO, WH	II	3		Low shrub
Thymelaeaceae	*Pimelea linifolia* subsp. *linifolia*	DSF, GW	V		3	Low shrub
Thymelaeaceae	*Pimelea neo-anglica*	DSF, GW	V			Low shrub
Thymelaeaceae	*Pimelea sp. 'Long Point'*	GW	II			Low shrub
Trimeniaceae	*Trimenia moorei*	RF	VI			Vine
Urticaceae	*Dendrocnide excelsa*	RF	II			Tree
Vitaceae	*Cissus hypoglauca*	RF	VI			Vine
Vitaceae	*Tetrastigma nitens*	RF	IV			Vine
Winteraceae	*Tasmannia insipida*	WSF, RF	V			Low shrub
Winteraceae	*Tasmannia stipitata*	WSF, RF	IV			Tall shrub
Xanthorrhoeaceae	*Xanthorrhoea sp.* Gibraltar Range	WSF	VII			Tall shrub
Xanthorrhoeaceae	*Xanthorrhoeo glauca* subsp. *angustifolia*	DSF	VII		2	Tall shrub
Xanthorrhoeaceae	*Xanthorrhoea johnsonii*	DSF	VII		2	Tall shrub
Zamiaceae	*Macrozamia plurinervia*	DSF	VII			Low shrub

Vegetation and floristics of Columbey National Park, lower Hunter Valley, New South Wales

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Abstract: A vegetation survey was undertaken within Columbey National Park (32° 35'S, 151° 44'E) near Clarence Town in the lower Hunter Valley of New South Wales. Multivariate cluster analysis and non-metric multi-dimensional scaling were carried out on plot-based data to classify the vegetation into twelve native communities (one plantation), and each compared with a larger regional dataset. A vegetation map was also prepared, based heavily on extensive ground-data supplemented with aerial photographic interpretation.

Although small in size, this reserve conserves good examples of the endangered Lower Hunter Spotted Gum-Ironbark Forest (475 ha) and River-Flat Eucalypt Forest on Coastal Floodplains (124 ha), together with a small parcel of Hunter Lowlands Redgum Forest (3.7 ha). Collectively, these Endangered Ecological Communities occupy approximately 70% of the 870 ha reserve. Small populations of the threatened and previously unreserved orchid, *Pterostylis chaetophora* are present in the reserve, together with the Endangered *Corybas dowlingii* and the regionally significant cycad, *Macrozamia flexuosa*. An historical record of *Eucalyptus glaucina* could not be substantiated during the current survey, and may have been recorded in error. A total of 349 vascular plant taxa were recorded, including 25 weed species.

The vegetation present within Columbey National Park bears strong resemblance to that in the Cessnock region of the Hunter Valley (Bell 2004; DECC 2008), a feature attributed to similar rainfall and soil types. Vegetation communities common between the two areas include Lower Hunter Spotted Gum – Ironbark Forest, Red Ironbark Scrub-Forest, Paperbark Soak Forest, Floodplain Redgum-Box Forest and Gully Rainforest. Unlike the Cessnock area, however, Columbey has not been subject to illegal rubbish dumping to any great degree.

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Introduction

Columbey National Park (NP) conserves approximately 870 ha of land adjacent to the township of Clarence Town in the lower Hunter Valley. It was proclaimed in July 2007 and occupies the majority of the former Uffington State Forest. Investigations as part of a larger study reviewing the status and distribution of the endangered Lower Hunter Spotted Gum – Ironbark Forest (Bell in prog.) prompted a full floristic survey and classification to be undertaken within the reserve, on behalf of the NSW Department of Environment and Climate Change.

Location and environmental Setting

Columbey National Park (32° 35' S, 151° 44' E) is located immediately west of Clarence Town, on the lower Williams River in the Hunter Valley, within the local government areas of Dungog and Port Stephens (Figure 1). The majority of the reserve (788 ha) lies between the south-easterly flowing Wallaroo Creek and the Newcastle-Chichester water pipeline, with a smaller separate portion (81 ha) at Stonequarry Hill approximately 2km to the west. Topography in the major portion ranges from approximately 10 m ASL in the south, to 100 m ASL at Tower Hill in the centre of the reserve. At Stonequarry Hill, the more rugged terrain ranges from 40m – 160 m ASL. Columbey Sugarloaf, rising to a height of 218 m, lies approximately 1km west of the reserve, and Wallaroo Nature Reserve occurs 5 km to the south-east. The entire reserve drains via Wallaroo and Tumbledown Creeks into the Williams River.

The geology of the area is predominantly Carboniferous in age, with the sandstone-dominated Wallaringa Formation of the Tamworth fold belt the most widespread lithology. Stonequarry Hill is entirely comprised of the conglomerate-dominated Mount Johnstone Formation (DMR 1999). Major creeklines in the reserve, such as Wallaroo Creek and tributaries of Tumbledown Creek, support often deep

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deposits of alluvium. Soil landscapes have been mapped and described by Matthei (1995), and are dominated (~80%) by moderately deep, well-to-imperfectly drained Yellow Soloths, and shallow moderately-drained Lithosols of the Clarence Town soil landscape. Other less common soil types include deep well-drained Yellow and Brown Soloths and rapidly-drained Lithosols and Bleached Loams (~13%); and well-drained and moderately deep alluvium on alluvial plains, and deep well-drained siliceous sands in stream channels (~7%).

The Hunter Valley falls within a warm temperate climatic zone, with a maritime influence near the coast, and experiences warm wet summers and cool dry winters. Rainfall generally peaks in late Summer and early Autumn, although local variations due to topography are evident. Annual average rainfall ranges from 925 mm at Paterson (10km west) to 1152 mm in Wallaroo State Forest (14km east). Temperatures range from a daily average low of 6° C in July, to a high of 29.6 ° C in January (Bureau of Meteorology 2008).

Previous botanical studies

Little previous botanical survey has been carried out within Columbey. Prior to dedication as a National Park, parts of Uffington State Forest were sampled for regional vegetation classification and mapping studies (eg: North Coast CRA, LHCCREMS); however no comprehensive study has been completed. Significant plant species previously recorded from the general area around Columbey include *Angophora inopina, Callistemon linearifolius, Cynanchum elegans, Diuris pedunculata, Eucalyptus glaucina, Grevillea parviflora* subsp. *parviflora, Syzygium paniculatum, Tetratheca juncea* (all threatened), and *Macrozamia flexuosa, Eucalyptus fergusonii* subsp. *fergusonii* (rare) (NSW Wildlife Atlas, April 2009). *Eucalyptus glaucina* has been previously recorded from the reserve area, although the two records date from 1893 and 1906 and their precise locations are unclear. Vegetation within the nearby Wallaroo Nature Reserve is documented in Bell (2002).

Methods

Floristic survey

Vegetation survey was predominantly conducted in Columbey in October and November 2008, with additional sampling in April and May 2009. Sampling plots were surveyed across all parts of the reserve, and locations were selected on the basis of major observed differences in the vegetation so that all variations present could be examined. This entailed an initial reconnaissance of the entire reserve prior to sampling (facilitated by the profusion of fire trails present), followed by allocation of sampling plots in representative locations and with as many replicates as possible. Sampling was also undertaken in previously mapped soil and lithology types. All sample plots were of 0.04 ha (nominally 20 x 20 m, or 40 x 10 m in riparian areas) and located within homogeneous stands of vegetation. Modified (1–6 scale: 1 = few

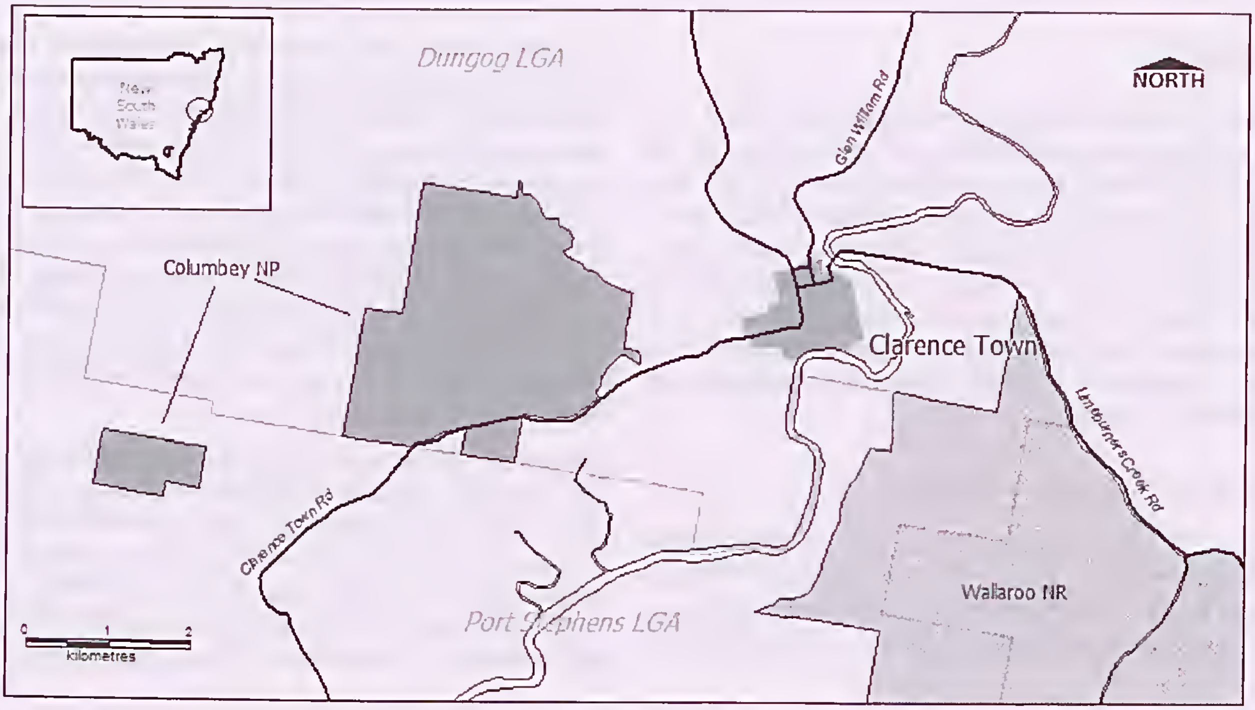

Fig. 1. Location of Columbey National Park.

individuals, <5% cover; 2 = many individuals, <5% cover; 3 = 5–25% cover; 4 = 26–50% cover; 5 = 51–75% cover; 6 = 76–100% cover) Braun-Blanquet cover abundance scores (Braun Blanquet 1928) were applied to all vascular plant species recorded within each quadrat. Plant nomenclature followed Harden (1990–1993) and revisions accepted by the National Herbarium of New South Wales (via the PlantNet web site http://plantnet.rbgsyd.nsw.gov.au). Structural data were also collected at each sample plot, including estimated height range, percentage cover and dominant species present in each observable stratum.

Data analysis & community definition

Cluster analysis and non-metric multidimensional scaling (nMDS) were performed on the dataset using *Primer* V6 (Clarke & Gorley 2006), utilizing the group averaging strategy, the Bray-Curtis association measure and a Beta value of –0.1. The SIMPER routine in *Primer* was used to generate diagnostic species lists for each defined floristic group, by decomposing average Bray-Curtis dissimilarities between all pairs of samples (one from each defined group) into percentage contributions from each species. Analysis of similarity within and between pre-defined floristic groups was undertaken with the ANOSIM routine in *Primer*, by testing the null hypothesis that there were no floristic differences between samples within the defined groups.

Targeted survey

Threatened species searches were conducted in concert with full floristic plot sampling, as well as through targeted searches in habitats known to support specific species elsewhere. Foot traverses in selected areas were made with a hand-held GPS unit (Garmin GPSmap 60CSx) and significant plant species recorded where encountered. GPS data was downloaded and imported into mapping layers on completion of each field search. Particular searches were made along drainage lines for *Eucalyptus glaucina*, given the pre-existing record near the southern boundary of the reserve. In this case, most drainage lines in the southern half of the reserve were searched, and all redgums encountered in the field were identified through general habit, leaf colour (extent of glaucousness) and fruit/bud morphology. Binoculars were used to assist in examining canopy characteristics.

Vegetation Community mapping

Mapping of vegetation communities was accomplished through the collection of dominant species information at numerous locations throughout the reserve. These Rapid Data Points (RDPs) are essentially summaries of floristic information tied to a specific ground location using a Garmin GPSmap 60CSx, and later transferred to the GIS. Information recorded included canopy, shrub and ground

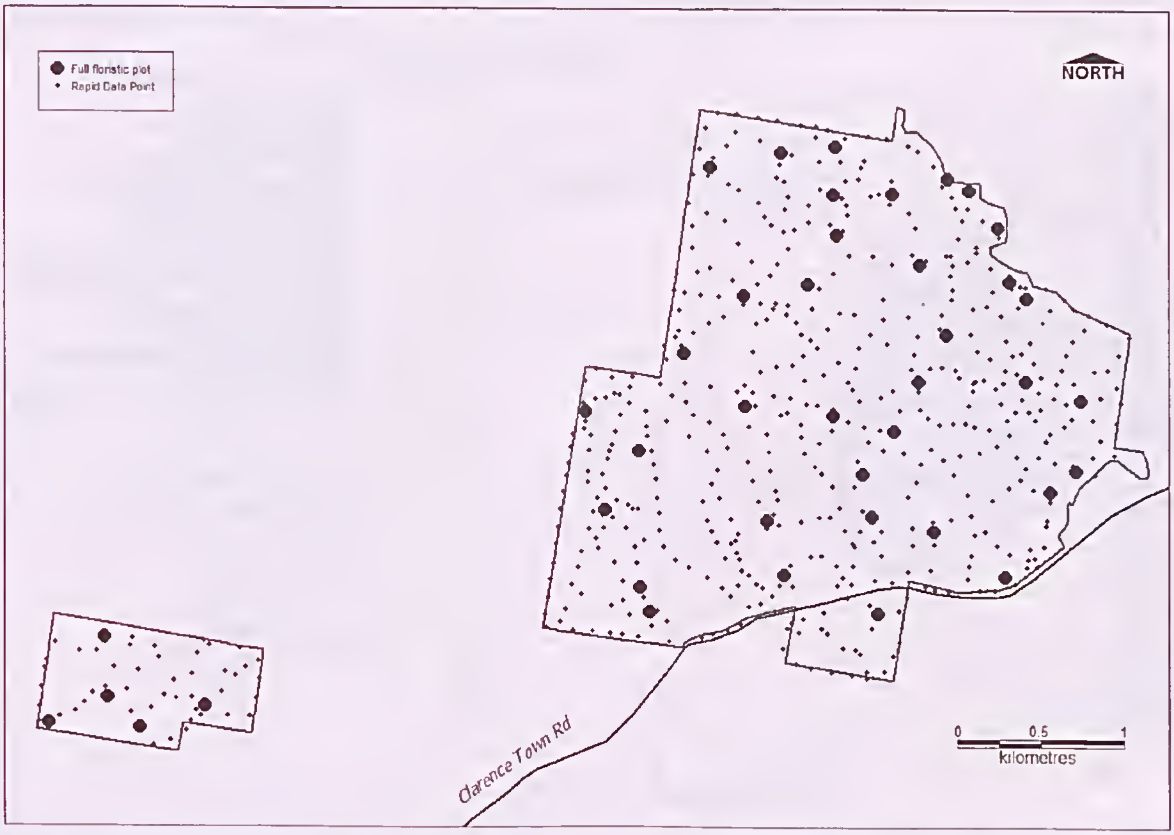

Fig. 2. Distribution of Rapid Data Points (RDPs) (small dots) and full floristic plots (large dots) across Columbey National Park.

dominants, together with miscellaneous notes on condition and a field-applied vegetation community code. Initially, all trafficable paths across the study area were driven in 4WD vehicle recording RDPs. Those areas lacking extensive trail networks, including poorly maintained fire trails, were then traversed on foot with a hand-held GPS unit, recording the same information. A large dataset of summary information was rapidly collected to use in vegetation mapping procedures.

During field reconnaissance 550 Rapid Data Points (RDPs; 1 point per 0.63 ha) were collected in Columbey NP (Figure 2). At each of these points, information on dominant plant species in each stratum was recorded and imported directly into the vegetation mapping process. All points were initially given a draft vegetation community code in the field, which was reviewed after classification analysis of full floristic data.

Within Mapinfo© Geographical Information System (GIS), observable photo-patterns from orthorectified colour aerial photographs (1:25000 scale, supplied by LPI) were scrutinised and cross-referenced to RDP data collected in the field. All RDP data collected and recorded on GPS was attributed a map unit code reflecting the final floristic classification, and overlain on the base map to check and code each polygon accordingly.

Results

Sampling intensity & species diversity

A total of 42 full floristic sampling plots were completed as part of this study (see Figure 2 for locations). One sampling plot was located within Crown reserve along Cemetery Road to the east of the reserve, but was included in the analysis due to its close proximity. This intensity of sampling represents approximately one sample per 21 hectares of vegetation. There were 349 taxa were recorded in Columbey NP reserve including 25 weed species. The most common species recorded across all sampling plots were the grasses *Microlaena stipoides* var. *stipoides*, *Entolasia stricta* and *Aristida vagans*, and the herbs *Pratia purpurascens*, *Brunoniella australis* and *Dichondra repens*. *Cheilanthes sieberi* subsp. *sieberi* was the most commonly recorded fern, while *Leucopogon juniperinus*, *Notelaea longifolia* forma *longifolia* and *Bursaria spinosa* were the most frequent shrubs. *Corymbia maculata* was the most frequent canopy species. A full species list for Columbey is given in Appendix 1.

Data analysis and vegetation mapping

Multivariate cluster analysis of 42 sample plots and 325 native plant taxa resulted in the definition of 6 major groups

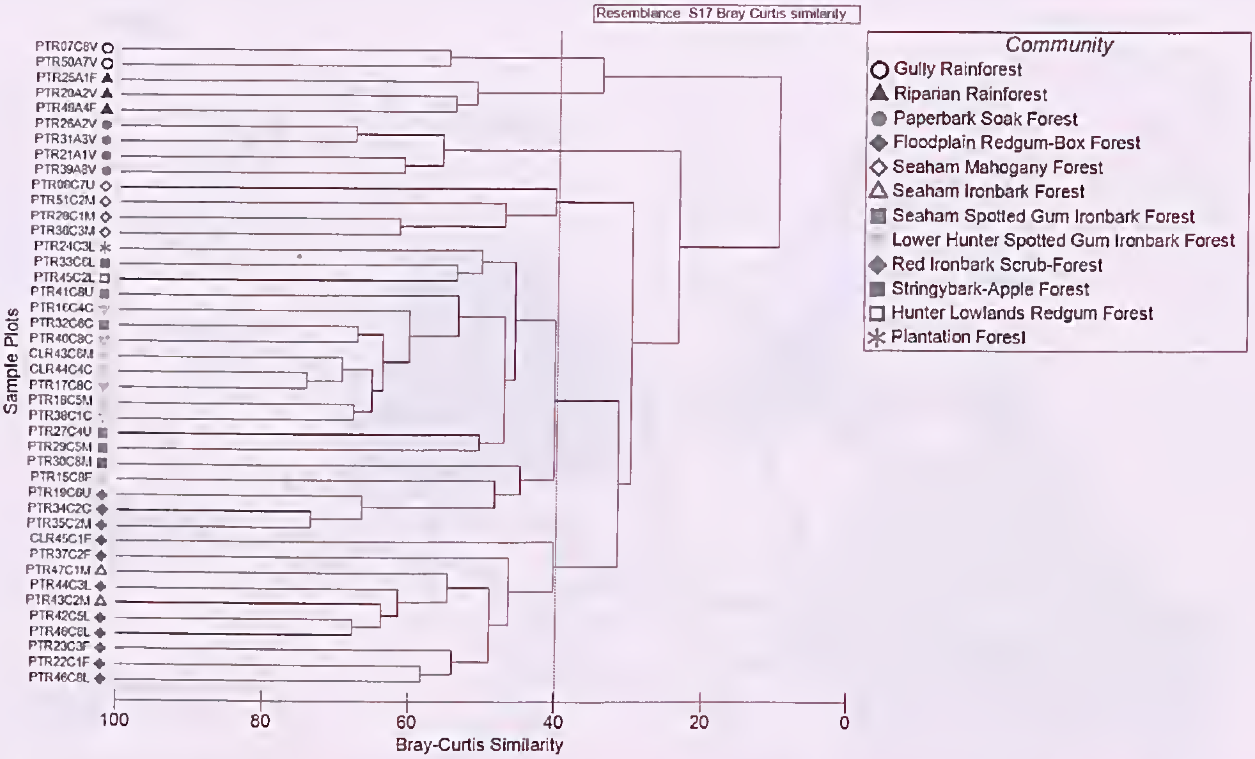

Fig. 3. Site dendrogram showing the relationship between all sample plots (Bray-Curtis association measure). Floristic groups defined at 40% similarity (vertical dotted line).

at 40% similarity, or 0.60 dissimilarity (Figure 3). On further interrogation, one of these groups can be further divided into 6 finer-scale groups, although some of these are poorly defined due to lack of sample replication. This represents a fine resolution of observable floristic variation, with other classifications often limited to 20–30% similarity (0.7–0.8 dissimilarity). Five of the 12 ultimate groups have been previously defined in the LHCC regional classification (which excludes Dungog LGA: NPWS 2000), while one represents a former forestry plantation. Sample plot PTR45C2L comprises a small area of regrowing *Eucalyptus tereticornis* forest on a lower slope, which grouped closest to the single plot comprising the Plantation Forest (PTR24C3L) and one of the Stringybark-Apple forest plots, dominated by *Eucalyptus globoidea* (PTR33C6L). Plots comprising the closely related Lower Hunter Spotted Gum-Ironbark Forest, Seaham Spotted Gum-Ironbark Forest, and the Red Ironbark Scrub-Forest were not clearly defined in the cluster analysis, although the nMDS ordination provided better resolution of these communities. The two plots comprising the Seaham Ironbark Forest (PTR43C2M, PTR47C1M) had both been impacted upon by grazing activities in the past, and grouped within the Floodplain Redgum-Box Forest group. This is understandable given the dominance of grasses and herbs in these two communities. Four distinct forms of Floodplain Redgum-Box Forest are recognisable in the field (Cabbage Gum forest, Grey Box forest, Forest Redgum forest, and Ironbark forest); however the history of grazing and other disturbances did not allow a consistent pattern to emerge in the cluster analysis. Non-metric multidimensional scaling strongly supported the groupings evident in the cluster analysis, with a low stress level of 0.11 and strong congruence with the cluster analysis groups (Figure 4). All defined groups are well separated in 2-dimensional space, with the exception of the closely related Spotted Gum – Ironbark communities, and the Floodplain Redgum-Box Forest group noted above. Note the location of the four Seaham Spotted Gum – Ironbark Forest sample plots compared to their positions in the cluster analysis (Figure 3).

The analysis of similarity of species composition between defined groups of sample plots revealed an overall Global R value of 0.882 ($p = 0.001$). Significant differences were also evident between all defined communities in the pairwise analysis, except for Plantation Forest which had only one sample (Table 2). Comparisons from most groups returned R values at or close to unity, indicating within group similarity to be greater than between group similarity. Low values evident for Seaham Mahogany Forest with Seaham Spotted Gum – Ironbark Forest (0.56), and the latter community with Lower Hunter Spotted Gum-Ironbark Forest (0.58), Floodplain Redgum-Box Forest (0.62), and Plantation Forest (0.67) suggest poorer resolution of these communities when based on floristic differences alone, and low sample replication may have contributed to this result. The R value of –0.08 between Seaham Ironbark Forest and Floodplain Redgum-Box Forest suggests no floristic difference between these two communities, however the two occur in differing environments (slopes vs floodplain) and have been retained as separate communities on this basis.

Vegetation Community profiles of each vegetation community in Columbey National Park are provided in

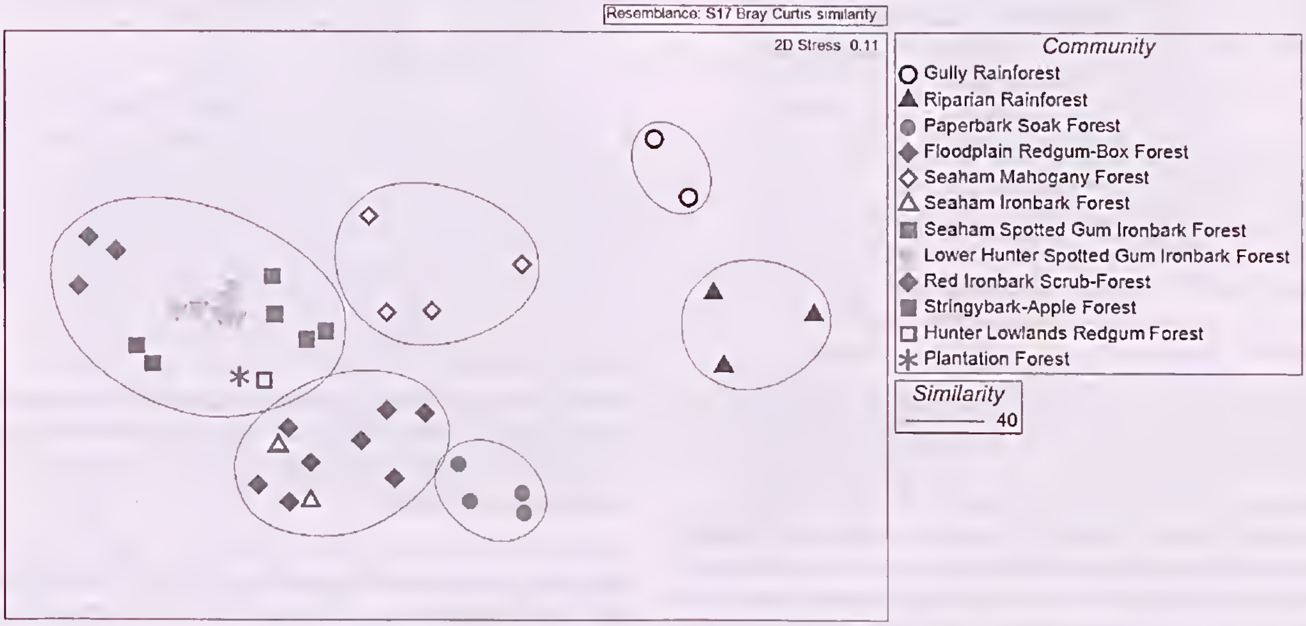

Fig. 4. nMDS plot showing the relationship between all sample plots, overlain with cluster analysis groups (40% similarity, Bray-Curtis association measure) from Figure 3.

Table 2. ANOSIM results (Global R values) for pair-wise comparisons of *aprior* vegetation groups.

	LHSGIF	FRBF	GR	SMF	RIS-F	RR	PSF	PF	SSGIF	SAF	SIF	HLRF
LHSGIF												
FRBF	0.97											
GR	1	1										
SMF	0.97	0.87	0.96									
RIS-F	0.95	1	1	1								
RR	1	1	1	1	1							
PSF	1	0.90	1	0.99	1	1						
PF	0.92	0.88	1	0.75	1	1	1					
SSGIF	0.58	0.62	1	0.56	1	1	1	0.67				
SAF	0.90	0.99	1	1	1	1	1	1	1			
SIF	1	-0.08	1	0.96	1	1	1	1	0.93	1		
HLRF	0.79	0.59	1	0.83	1	1	1	-	0.75	0.00	1	

LHSGIF = Lower Hunter Spotted Gum – Ironbark Forest
FRBF = Floodplain Redgum – Box Forest
GR = Gully Rainforest
SMF = Seaham Mahogany Forest
RIS-F = Red Ironbark Scrub-Forest
RR = Riparian Rainforest
PSF = Paperbark Soak Forest
PF = Plantation Forest
SSGIF = Seaham Spotted Gum – Ironbark Forest
SAF = Stringybark – Apple Forest
SIF = Ironbark Forest
HLRF = Hunter Lowlands Redgum Forest

Table 4 Vegetation community extent, Columbey NP.

Unit	Community	Extent (ha)	% of total
1	Gully Rainforest	7	0.8
2	Riparian Rainforest	20	2
3	Paperbark Soak Forest	5	0.6
4	Floodplain Redgum – Box Forest	124	15
5	Seaham Mahogany Forest	39	5
6	Seaham Ironbark Forest	8	1
7	Seaham Spotted Gum – Ironbark Forest	107	13
8	Lower Hunter Spotted Gum – Ironbark Forest	419	52
9	Red Ironbark Scrub-Forest	56	7
10	Stringybark – Apple Forest	3	0.3
11	Hunter Lowlands Redgum Forest	4	0.5
12	Plantation Forest	17	2
D	Dam	0.1	0.01
Xr	Disturbed: Canopy only	2	0.2
Total		810	100

Appendix 2. These include lists of those species contributing the top 90% in diversity for each, as obtained through the SIMPER procedure in *Primer*. Community profiles provide information to enable identification of that community in the field including a summary map showing the distribution of each community within the reserve. For each vegetation community, a summary of the basic structural makeup of that unit is given. The accuracy of structural information presented with each profile is governed by the sample size of each community (shown as "n" in the structural tables). Where possible, the equivalent vegetation classification within other regional assessments have been provided under the community name, to assist in regional comparisons and significance assessments.

A vegetation map for Columbey National Park (Figure 5), based on aerial photo interpretation, floristic classification and detailed ground reconnaissance shows the distribution of vegetation communities. The areal extent of each community within the reserve is shown in Table 4. Brief descriptions of the communities defined for Columbey are given below.

1. Gully Rainforest: noted only in the more rugged topography of the Stonequarry Hill section, this community is dominated by *Backhousia myrtifolia, Scolopia braunii, Melaleuca styphelioides, Syzygium australe* and *Streblus brunonianus* in the canopy, over a range of rainforest-affiliated species such as *Hibiscus heterophyllous, Dioscorea transversa, Myrsine variabilis, Podocarpus elatus, Elaeodendron australis, Lomandra longifolia* and *Pellaea falcata*. Emergent eucalypts from the surrounding landscape are also evident, including *Corymbia maculata, Eucalyptus acmenoides, Eucalyptus canaliculata* and *Eucalyptus moluccana*.

2. Riparian Rainforest: narrowly occurring along major creeklines such as Wallaroo Creek, on deep sandy alluvium. Dominated by *Tristaniopsis laurina, Backhousia myrtifolia, Melicope micrococca, Acronychia wilcoxianum, Acmena smithii,* and *Cryptocarya microneura*. Emergent eucalypts (eg: *Eucalyptus acmenoides, Eucalyptus tereticornis*) are also present, as are the occasional *Casuarina cunninghamiana* and **Grevillea robusta*. The latter species does not naturally occur south of Coffs Harbour on the far North Coast (Hill 2002), and hence the presence in Columbey is likely to have dispersed from the nearby Clarence Town village where it has been widely planted.

3. Paperbark Soak Forest: occurs along drainage lines and is dominated by *Melaleuca linariifolia*, occasionally with *Melaleuca styphelioides*, over a dense ground layer of *Carex longebrachiata, Carex appressa* and other sedge species. Emergent eucalypts (*Eucalyptus tereticornis, Eucalyptus amplifolia* subsp. *amplifolia, Eucalyptus siderophloia*) are also present in many locations. Many small examples of this community occur within the Floodplain Redgum-Box Forest.

4. Floodplain Redgum – Box Forest: restricted to major creeklines and their associated flood-outs. It can be dominated by any of *Eucalyptus amplifolia* subsp. *amplifolia, Eucalyptus siderophloia, Eucalyptus tereticornis* or *Eucalyptus moluccana*. Examples dominated by each are present within the reserve, which are readily recognised in the field. *Angophora floribunda* also occurs as a canopy dominant in limited areas. Some locations have been previously cleared and now support regrowth vegetation, while others show few signs of disturbance. This community is consistent with the River-Flat Eucalypt Forest on Coastal Floodplains EEC (NSW Scientific Committee 2005a).

5. Seaham Mahogany Forest: dominated by *Eucalyptus acmenoides, Eucalyptus siderophloia* and *Allocasuarina torulosa*, this community occurs on well sheltered slopes such as the southern side of Tower Hill. The understorey is dominated by *Notelaea longifolia* forma *longifolia* and includes a high diversity of grasses and herbs such as *Microlaena stipoides* var. *stipoides, Oplismenus imbecillus, Desmodium gunnii, Pratia purpurascens, Veronica plebeia* and *Scutellaria humilis*.

6. Seaham Ironbark Forest: located in two areas of the reserve, both of which have been disturbed by previous clearing and grazing, and both are dominated by even-aged stands of *Eucalyptus crebra* and/ or *Eucalyptus siderophloia*. Shrubs are generally sparse or absent, but a diverse ground layer of grasses and herbs is present. It is probable that this community is an artifact of past clearing, and has been recolonised by nearby standing remnant trees, particularly *Eucalyptus crebra*.

7. Seaham Spotted Gum – Ironbark Forest: dominated by *Eucalyptus siderophloia, Eucalyptus crebra, Corymbia maculata* and *Eucalyptus moluccana*, often with *Eucalyptus tereticornis*. Occurs on the higher ridges and hills, such as Tower Hill. Understorey species include *Bursaria spinosa, Acacia falcata, Lissanthe strigosa, Jacksonia scoparia, Cymbopogon refractus, Themeda australis, Aristida vagans*, and a high diversity of herbs.

8. Lower Hunter Spotted Gum – Ironbark Forest: dominated by *Eucalyptus fibrosa, Corymbia maculata* and *Eucalyptus umbra*. In places, *Eucalyptus moluccana* can also be present. Tends to occur on the lower undulating slopes at low elevation, with typical understorey species including *Daviesia ulicifolia* subsp. *ulicifolia, Bursaria spinosa, Pultenaea villosa, Entolasia stricta, Aristida vagans, Macrozamia flexuosa*, and *Lomandra confertifolia* subsp. *pallida*. This community is consistent with the Final Determination for the EEC of the same name (NSW Scientific Committee 2005b), and was supported in the data analysis.

9. Red Ironbark Scrub-Forest: dominated by *Eucalyptus fibrosa* over a dense understorey of *Melaleuca nodosa*. *Corymbia maculata* may also be present but in very low abundance. This community occurs toward the north of the reserve, and supports a number of species such as *Phyllota phylicoides, Lomandra glauca, Gompholobium pinnatum, Patersonia sericea, Dillwynia retorta, Xanthorrhoea latifolia* subsp. *latifolia* and *Banksia spinulosa* var. *collina*, which in the lower Hunter Valley occur more commonly on sandstone substrates.

10. Stringybark – Apple Forest: occurs in two locations within the wider LHSGIF landscape. Dominated by *Eucalyptus globoidea*, but with *Angophora costata* or *Eucalyptus fibrosa* present in one area. This community is typified by the presence of more typical sandstone species, such as *Banksia spinulosa*

var. *collina, Xanthorrhoea latifolia, Podolobium scandens, Laxmannia gracilis, Gompholobium pinnatum* and *Aristida warburgii*. Given the small size of both locations present, it is not surprising that their floristic composition is heavily influenced by the surrounding LHSGIF, hence their close ties to that community in the data analysis.

11. Hunter Lowlands Redgum Forest: a single location of this community occurs in a previously cleared and grazed landscape. Dominated by *Eucalyptus tereticornis* over a grassy ground layer of *Themeda australis, Aristida warburgii, Aristida vagans* and *Ptilothrix deusta*. Shrubs such as *Acacia falcata, Acacia irrorata, Pultenaea villosa* and *Bursaria spinosa* are also present. The floristic composition present at this site is consistent with the Final Determination for the EEC of the same name (NSW Scientific Committee 2003).
12. Plantation Forest: between Plantation Road and Clarencetown Road, areas of plantation eucalypt forest occur, in mostly well-defined rows. For all intents and purposes these areas possess a native understorey of species typical of elsewhere in the reserve. Planted eucalypts noted include all locally occurring species, such as *Eucalyptus siderophloia* (dominant), *Eucalyptus fibrosa, Eucalyptus tereticornis, Eucalyptus moluccana* and *Corymbia maculata*. An area of *Callitris endlicheri* (not locally endemic) is also present adjacent to Clarencetown Road. Other areas of plantation include *Eucalyptus resinifera*, particularly towards the middle of the reserve.

Discussion

Conservation significance of vegetation communities

For Columbey National Park 12 vegetation communities have been delineated using multivariate clustering and nMDS techniques, including one plantation forest type. For a small reserve this shows surprising diversity, ranging from riparian rainforest on deep alluvial soils to dryer open forests on hard-setting clays. There were 349 native plant species including 25 weed species recorded for the reserve.

Three Endangered Ecological Communities are present within Columbey NP. Collectively these occupy just over

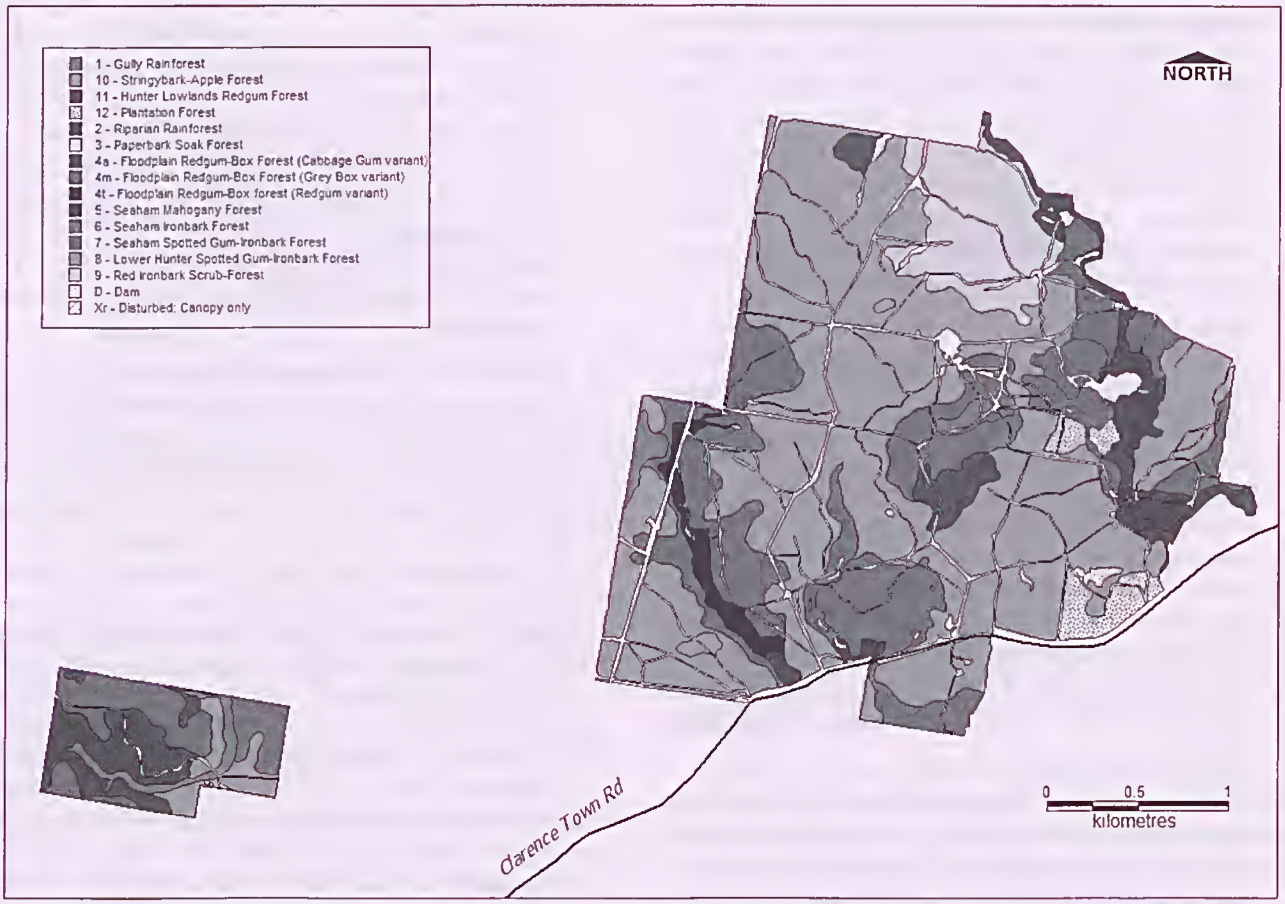
1 - Gully Rainforest
10 - Stringybark-Apple Forest
11 - Hunter Lowlands Redgum Forest
12 - Plantation Forest
2 - Riparian Rainforest
3 - Paperbark Soak Forest
4a - Floodplain Redgum-Box Forest (Cabbage Gum variant)
4m - Floodplain Redgum-Box Forest (Grey Box variant)
4t - Floodplain Redgum-Box forest (Redgum variant)
5 - Seaham Mahogany Forest
6 - Seaham Ironbark Forest
7 - Seaham Spotted Gum-Ironbark Forest
8 - Lower Hunter Spotted Gum-Ironbark Forest
9 - Red Ironbark Scrub-Forest
D - Dam
Xr - Disturbed: Canopy only
NORTH
Clarence Town Rd
0
0.5
1
kilometres

Fig. 5. Vegetation map of Columbey National Park.

600 ha or 69% of the entire reserve (Table 6, Figure 6). Sizeable areas of Lower Hunter Spotted Gum – Ironbark Forest (including the Red Ironbark Scrub-Forest) occur across the reserve area and are significant for conserving this EEC near its northern limit of distribution. Only Werakata National Park and State Conservation Area near Cessnock support this EEC elsewhere (Bell 2004; DECC 2008).

The various forms of Floodplain Redgum-Box Forest occurring along major creek lines and flood-outs support vegetation broadly ascribable to the River-Flat Forest on Coastal Floodplains EEC. While broad in nature, this EEC encapsulates vegetation associated with major drainage lines and which traditionally have been cleared or disturbed for agriculture. The presence of *Eucalyptus amplifolia, Angophora floribunda, Eucalyptus tereticornis* and *Eucalyptus moluccana* in these environments within the reserve typifies this community.

Hunter Lowlands Redgum Forest represents the third EEC present, typified by *Eucalyptus tereticornis* on gentle rises, which like Werakata National Park (Bell 2004) is represented in Columbey only by a small stand. Some heavily disturbed lands within Columbey may also potentially be included within listed EECs, but require more detailed site assessment (shown on Figure 6).

The vegetation present within Columbey National Park bears strong resemblance to that in the Cessnock region of the Hunter Valley (Bell 2004; DECC 2008). This is perhaps

Table 6. Extent of Endangered Ecological Communities, Columbey National Park.

Endangered Ecological Community	**Extent (ha)**
Lower Hunter Spotted Gum – Ironbark Forest	475
River Flat Eucalypt Forest on Coastal Floodplains	124
Hunter Lowlands Redgum Forest	3.7
Total	603

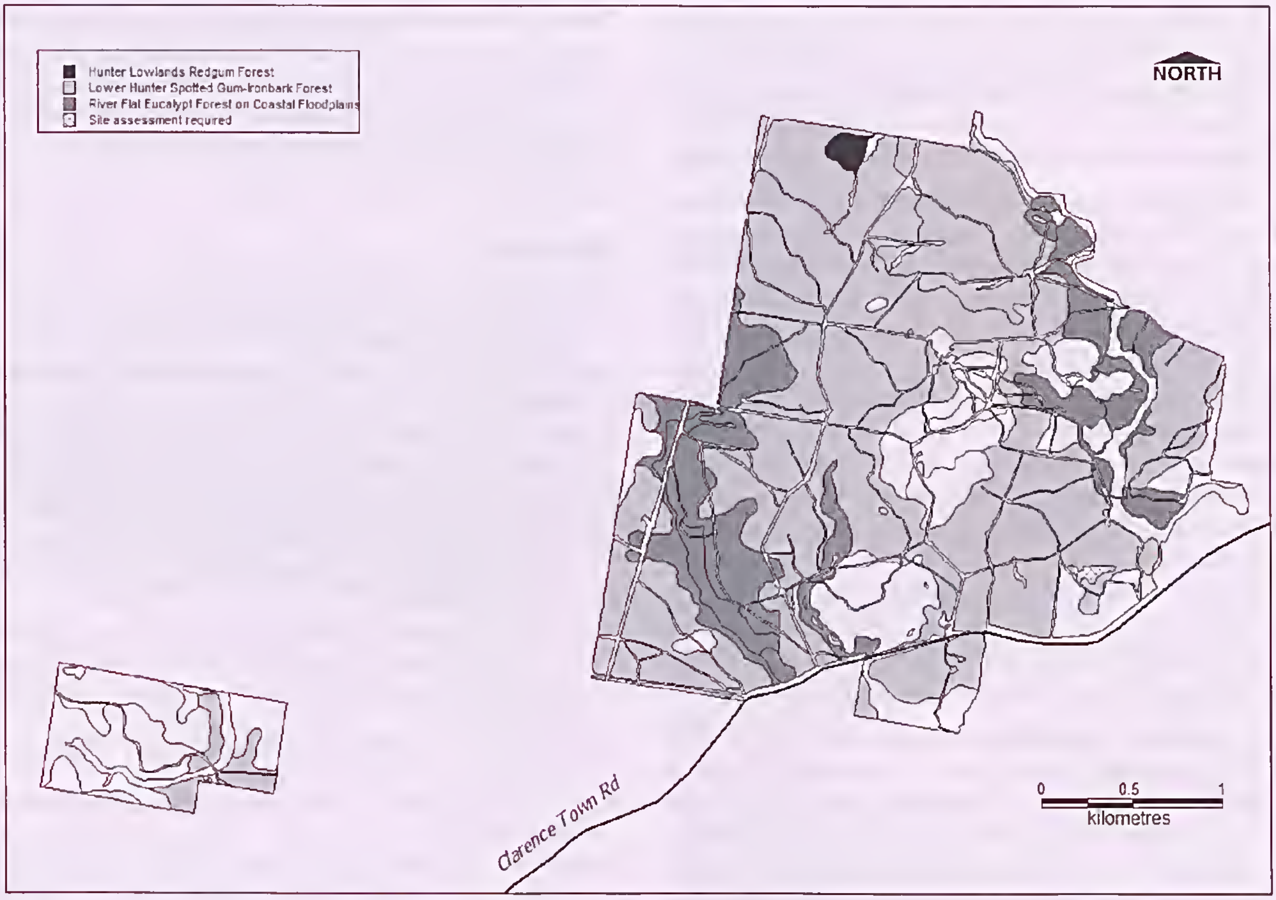
■ Hunter Lowlands Redgum Forest
☐ Lower Hunter Spotted Gum-Ironbark Forest
▨ River Flat Eucalypt Forest on Coastal Floodplains
☐ Site assessment required
NORTH
Clarence Town Rd
0
0.5
1
kilometres

Fig. 6. Endangered Ecological Communities mapped for Columbey NP.

not surprising given the two locations lie in the same rainfall band (900–1000 mm/yr) and occur on similar geologies. Vegetation communities common between the two areas include Lower Hunter Spotted Gum – Ironbark Forest, Red Ironbark Scrub-Forest, Paperbark Soak Forest, Floodplain Redgum-Box Forest and Gully Rainforest. Unlike the Cessnock area, however, Columbey has not been subject to illegal rubbish dumping to any great degree.

Significant plant species

One small population (~5 plants) of the terrestrial orchid *Pterostylis chaetophora* was recorded in Columbey NP during the survey. *Pterostylis chaetophora* (nominated as Endangered to the NSW *Threatened Species Conservation Act 1995*: *TSC Act 1995*) was recorded in Columbey National Park during the survey. This species was present in regrowth *Eucalyptus amplifolia* subsp. *amplifolia* forest, and is part of a known population in the Seaham-Clarence Town district. Several other populations, ranging in size from 2–20 plants, are also known from the reserve. The total NSW population of this species is estimated at 500–600 plants, with few populations exceeding 30 plants (A. Paget, pers. comm.).

A single population of *Corybas dowlingii* (Orchidaceae) (Endangered, *TSC Act 1995*) has been recorded in Columbey NP (B.Abbott, pers. comm.). No other populations are known from any other dedicated conservation reserve.

Many plants of the rare cycad *Macrozamia flexuosa* (Zamiaceae) (ROTAP 2K) were recorded in Columbey during the survey. *Macrozamia flexuosa* was scattered mostly within open forest of *Corymbia maculata, Eucalyptus fibrosa* and *Eucalyptus umbra*, and is present across most forest habitats.

Despite targeted searches, no specimens of *Eucalyptus glaucina* (Myrtaceae) were located: leaf morphology and colour in all redgums inspected idenfied them as either *Eucalyptus tereticornis* or *Eucalyptus amplifolia*. At the time of survey (late October – November 2008), most trees has a flush of new growth which were easily viewed through binoculars for colour assessment. The drainage line where the pre-existing record of this species was recorded was also searched but no *Eucalyptus glaucina* could be located. The NSW Department of Environment, Climate Change and Water (DECCW) Wildlife Atlas shows many records of *Eucalyptus glaucina* to the west and north-west of Columbey NP, in the area around Vacy, Paterson and Dungog (see Jupp 2001). These areas are higher in the Williams River catchment than Columbey, and it is possible that the reserve does not support ideal habitat for this species.

Other plant taxa of significance recorded from Columbey include *Sannantha crassa* (prev. *Babingtonia*) (family Myrtaceae) recorded along creeklines (previous southern limit at Barrington Tops, with a risk category of 'priority for investigation': Bean 1999); *Lomandra hystrix* (Lomandraceae) in riparian rainforest along Wallaroo Creek (southerly range extension from Taree: Quirico 1993); and *Gompholobium inconspicuum* (Fabaceae) within Red Ironbark Scrub-Forest (northern extension of range from Singleton-Cessnock: Chappill et. al. 2008, DECC 2008).

Weed Management

Weed species within the reserve are relatively few, although some areas would benefit from some rehabilitation effort. **Lantana camara* is the most extensive woody weed present, occurring along some drainage lines (eg: near the Newcastle-Chichester pipeline) and on sheltered slopes in greater relief areas. The numerous herbaceous and grassy weeds will only ever become problematic after heavy ground disturbance, and should be monitored and controlled whenever major earthworks are undertaken. The Black Cypress Pine (**Callitris endlicheri*) plantation along Clarence Town Road, although showing signs of limited spread around the edges, is unlikely to pose a serious threat to native communities. This species is sensitive to fire and will be adequately controlled through wildfire events or via strategic burns. Several large trees of **Grevillea robusta*, native to riparian rainforests north from Coffs Harbour, may potentially cause management issues in the future. However their current location within the riparian rainforest makes removal difficult.

Acknowledgements

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Appendix 1. List of vascular plant species recorded in Columbey National Park , 2008–2009

(* = exotic or non-indigenous species)

Family, Genus & Species

Filicopsida (Ferns)

Adiantaceae
Adiantum aethiopicum
Adiantum hispidulum
Cheilanthes austrotenuifolia
Cheilanthes distans
Cheilanthes sieberi subsp. *sieberi*
Pellaea falcata
Pellaea paradoxa

Blechnaceae
Doodia aspera

Polypodiaceae
Platycerium bifurcatum
Pyrrosia rupestris

Cycadopsida (Cycads)
Zamiaceae
Macrozamia flexuosa
Macrozamia reducta

Coniferopsida (Conifers)
Araucariaceae
Araucaria bidwillii *

Cupressaceae
Callitris endlicheri *

Podocarpaceae
Podocarpus elatus

Magnoliopsida (Flowering plants)
Dicotyledons

Acanthaceae
Brunoniella australis
Pseuderanthemum variabile

Apiaceae
Centella asiatica
Daucus glochidiatus f. A
Hydrocotyle laxiflora
Hydrocotyle peduncularis

Aphanopetalaceae
Aphanopetalum resinosum
Apocynaceae
Gomphocarpus fruticosus *
Parsonsia straminea

Araliaceae
Polyscias sambucifolia subsp. *sambucifolia*

Asteraceae
Brachyscome multifida var. *multifida*
Cassinia uncata
Chrysocephalum apiculatum
Cirsium vulgare *
Conyza bonariensis *
Epaltes australis
Euchiton involucratus
Euchiton sphaericus
Facelis retusa *
Lagenophora stipitata
Ozothamnus diosmifolius
Senecio madagascariensis *
Sigesbeckia orientalis subsp. *orientalis*
Taraxacum officinale *
Vernonia cinerea var. *cinerea*

Family, Genus & Species

Vittadinia cuneata var. *cuneata*
Vittadinia sulcata

Bignoniaceae
Pandorea pandorana

Boraginaceae
Cynoglossum australe

Cactaceae
Opuntia stricta var. *stricta* *

Campanulaceae
Wahlenbergia communis
Wahlenbergia gracilis
Wahlenbergia stricta subsp. *stricta*

Casuarinaceae
Allocasuarina torulosa
Casuarina cunninghamiana subsp. *cunninghamiana*
Casuarina glauca

Celastraceae
Elaeodendron australe var. *australe*
Maytenus silvestris

Clusiaceae
Hypericum gramineum

Convolvulaceae
Dichondra repens
Polymeria calycina

Cunoniaceae
Aphanopetalum resinosum
Dilleniaceae
Hibbertia aspera subsp. *aspera*
Hibbertia diffusa
Hibbertia scandens

Droseraceae
Drosera auriculata

Ebenaceae
Diospyros australis

Elaeocarpaceae
Elaeocarpus obovatus

Ericaceae
Acrotriche divaricata
Leucopogon juniperinus
Lissanthe strigosa subsp. *subulata*
Monotoca scoparia

Euphorbiaceae
Claoxylon australe
Homalanthus populifolius

Fabaceae (Faboideae)
Daviesia ulicifolia subsp. *ulicifolia*
Desmodium brachypodum
Desmodium gunnii
Desmodium rhytidophyllum
Desmodium varians
Dillwynia retorta species complex
Glycine clandestina
Glycine microphylla
Glycine tabacina
Glycine tomentella
Gompholobium inconspicuum
Gompholobium pinnatum
Hardenbergia violacea
Hovea linearis
Indigofera australis
Jacksonia scoparia
Kennedia rubicunda
Mirbelia rubiifolia
Phyllota phylicoides
Podolobium scandens
Pultenaea euchila
Pultenaea myrtoides
Pultenaea villosa
Swainsona galegifolia
Zornia dyctiocarpa var. *dyctiocarpa*

Fabaceae (Mimosoideae)
Acacia falcata
Acacia implexa
Acacia irrorata subsp. *irrorata*
Acacia leiocalyx subsp. *leiocalyx*
Acacia longifolia subsp. *longifolia*
Acacia maidenii
Acacia ulicifolia

Flacourtiaceae
Scolopia braunii

Gentianaceae
Centaurium tenuiflorum *

Geraniaceae
Geranium homeanum

Goodeniaceae
Goodenia bellidifolia subsp. *bellidifolia*
Goodenia hederacea subsp. *hederacea*
Goodenia heterophylla subsp. *heterophylla*

Haloragaceae
Gonocarpus tetragynus
Haloragis heterophylla

Lamiaceae
Clerodendrum tomentosum
Mentha diemenica
Mentha satureioides
Plectranthus parviflorus
Scutellaria humilis

Lauraceae
Cassytha glabella f. glabella
Cryptocarya microneura

Lobeliaceae
Pratia purpurascens

Loganiaceae
Logania albiflora
Logania pusilla

Loranthaceae
Dendrophthoe vitellina

Malvaceae
Hibiscus heterophyllus subsp. *heterophyllus*
Pavonia hastata *
Sida rhombifolia *

Meliaceae
Melia azedarach
Synoum glandulosum subsp. *glandulosum*

Menispermaceae
Sarcopetalum harveyanum
Stephania japonica var. *discolor*

Moraceae
Ficus coronata
Streblus brunonianus

Myoporaceae
Eremophila debilis
Myrsinaceae
Anagallis arvensis *
Myrsine variabilis

Myrtaceae
Acmena smithii

Family, Genus & Species

Angophora costata
Angophora floribunda

Backhousia myrtifolia
Callistemon linearis
Callistemon rigidus
Callistemon salignus
Calytrix tetragona
Corymbia maculata
Eucalyptus acmenoides
Eucalyptus amplifolia subsp. *amplifolia*
Eucalyptus canaliculata
Eucalyptus crebra
Eucalyptus fibrosa
Eucalyptus globoidea
Eucalyptus moluccana
Eucalyptus placita
Eucalyptus punctata
Eucalyptus saligna
Eucalyptus siderophloia
Eucalyptus tereticornis
Eucalyptus umbra
Leptospermum polygalifolium subsp. *cismontanum*
Leptospermum polygalifolium subsp. *polygalifolium*
Leptospermum trinervium
Melaleuca decora
Melaleuca linariifolia
Melaleuca nodosa
Melaleuca quinquenervia *
Melaleuca styphelioides
Melaleuca thymifolia
Sannantha (prev. Babingtonia) crassa
Syncarpia glomulifera subsp. *glomulifera*
Syzygium australe
Tristaniopsis laurina

Oleaceae
Notelaea longifolia f. intermedia
Notelaea longifolia f. longifolia

Oxalidaceae
Oxalis perennans

Peperomiaceae
Peperomia blanda var. *floribunda*

Phyllanthaceae
Breynia oblongifolia
Glochidion ferdinandi var. *ferdinandi*
Phyllanthus hirtellus
Phyllanthus similis
Phyllanthus virgatus
Poranthera microphylla

Pittosporaceae
Billardiera scandens
Bursaria longisepala
Bursaria spinosa
Hymenosporum flavum
Pittosporum multiflorum
Pittosporum revolutum

Plantaginaceae
Plantago debilis
Plantago lanceolata *

Polygalaceae
Polygala japonica

Polygonaceae
Persicaria strigosa

Proteaceae
Banksia spinulosa var. *collina*
Grevillea robusta *
Hakea sericea
Persoonia linearis

Putranjivaceae
Drypetes deplanchei
Ranunculaceae
Clematis aristata
Clematis glycinoides var. *glycinoides*
Ranunculus inundatus
Ranunculus plebeius

Rosaceae
Rubus parvifolius

Rubiaceae
Canthium coprosmoides
Galium binifolium
Galium gaudichaudii
Galium propinquum
Morinda jasminoides
Opercularia aspera
Opercularia diphylla
Opercularia varia
Pomax umbellata
Richardia humistrata *
Richardia stellaris *

Rutaceae
Acronychia wilcoxiana
Melicope micrococca
Zieria smithii

Santalaceae
Exocarpos cupressiformis

Sapindaceae
Dodonaea triquetra
Guioa semiglauca

Scrophulariaceae
Veronica plebeia

Solanaceae
Duboisia myoporoides
Solanum prinophyllum
Solanum stelligerum

Stackhousiaceae
Stackhousia viminea

Sterculiaceae
Brachychiton populneus subsp. *populneus*
Commersonia fraseri

Stylidiaceae
Stylidium graminifolium

Thymelaeaceae
Pimelea linifolia subsp. *linifolia*

Ulmaceae
Trema tomentosa var. *viridis*

Verbenaceae
Lantana camara *
Verbena rigida var. *rigida* *

Violaceae
Hybanthus stellarioides
Viola banksii
Viola hederacea

Vitaceae
Cayratia clematidea
Cissus antarctica
Cissus hypoglauca
Cissus opaca
Tetrastigma nitens

Magnoliopsida (Flowering plants)
Monocotyledons

Anthericaceae
Arthropodium milleflorum
Arthropodium minus

Family, Genus & Species

Arthropodium sp. *B*
Caesia parviflora var. *parviflora*
Caesia parviflora var. *vittata*
Laxmannia gracilis
Thysanotus tuberosus subsp. *tuberosus*
Tricoryne elatior

Araceae
Gymnostachys anceps

Commelinaceae
Commelina cyanea
Murdannia graminea

Cyperaceae
Carex appressa
Carex inversa
Carex longebrachiata
Carex maculata
Chorizandra cymbaria
Cyperus enervis
Cyperus imbecillis
Cyperus laevis
Cyperus lucidus
Cyperus sesquiflorus *
Eleocharis dietrichiana
Fimbristylis dichotoma
Gahnia aspera
Gahnia clarkei
Gahnia melanocarpa
Isolepis inundata
Lepidosperma elatius
Lepidosperma laterale
Ptilothrix deusta
Schoenus apogon
Tetraria capillaris

Dioscoreaceae
Dioscorea transversa

Hypoxidaceae
Hypoxis hygrometrica var. *hygrometrica*
Hypoxis hygrometrica var. *villosisepala*

Iridaceae
Patersonia sericea
Sisyrinchium sp. *A* *

Juncaceae
Juncus continuus
Juncus planifolius
Juncus usitatus

Juncaginaceae
Triglochin procerum

Lomandraceae
Lomandra confertifolia subsp. *pallida*
Lomandra filiformis subsp. *coriacea*
Lomandra filiformis subsp. *filiformis*
Lomandra glauca
Lomandra hystrix
Lomandra longifolia
Lomandra multiflora subsp. *multiflora*

Luzuriagaceae
Eustrephus latifolius
Geitonoplesium cymosum

Orchidaceae
Acianthus fornicatus
Caladenia catenata
Calochilus sp.
Chiloglottis diphylla
Dipodium punctatum
Eriochilus cucullatus spp. agg.
Genoplesium sp.
Microtis unifolia
Pterostylis chaetophora
Pterostylis collina
Pterostylis longifolia
Spiranthes australis

Philydraceae
Philydrum lanuginosum

Phormiaceae
Dianella caerulea var. *assera*
Dianella caerulea var. *caerulea*
Dianella caerulea var. *cinerascens*
Dianella revoluta var. *revoluta*
Dianella tasmanica

Poaceae
Anisopogon avenaceus
Aristida ramosa
Aristida vagans
Aristida warburgii
Austrodanthonia setacea
Austrodanthonia tenuior
Axonopus fissifolius *
Bothriochloa decipiens var. *decipiens*
Chloris truncata *
Cymbopogon refractus
Cynodon dactylon
Dichelachne micrantha
Digitaria diffusa
Digitaria ramularis
Echinopogon caespitosus var. *caespitosus*
Echinopogon intermedius
Echinopogon ovatus
Entolasia marginata
Entolasia stricta
Eragrostis brownii
Eragrostis cilianensis *
Eragrostis leptostachya
Imperata cylindrica var. *major*
Joycea pallida
Lachnagrostis aemula
Microlaena stipoides var. *stipoides*
Notodanthonia longifolia
Oplismenus aemulus
Oplismenus imbecillis
Panicum effusum
Panicum simile
Paspalidium albovillosum
Paspalidium aversum
Paspalidium distans
Paspalum dilatatum *
Poa labillardierei var. *labillardierei*
Sarga leiocladum
Sporobolus creber
Sporobolus pyramidalis *
Themeda australis

Smilacaceae
Smilax australis
Smilax glyciphylla

Uvulariaceae
Tripladenia cunninghamii

Xanthorrhoeaceae
Xanthorrhoea glauca subsp. *glauca*
Xanthorrhoea latifolia subsp. *latifolia*
Xanthorrhoea macronema

Appendix 2. Vegetation Community Profiles for Columbey National Park

Vegetation Community profiles provide information to enable identification of that community in the field. A summary map showing the distribution of each community within the reserve is included with each profile. For each vegetation community, a summary of the basic structural makeup of that unit is given. The accuracy of structural information presented with each profile is governed by the sample size of each community (shown as "n" in the structural tables). Where possible, the equivalent vegetation classification within other regional assessments have been provided under the community name, to assist in regional comparisons and significance assessments.

The derivation of diagnostic species for each community has been defined using the SIMPER routine in *Primer*. SIMPER analysis provides the relative contributions of each species to the Bray-Curtis similarity within each of the defined vegetation communities. Only those species contributing to a total cumulative contribution of 90% of the average similarity (ie: the value shown at the top of each table) for each community are listed. These species can be described of as *typical* of that community, and have a consistently large presence within the data as reflected in the ratio of their contribution to the standard deviation (the Sim/SD field in each table) across the within-group similarities (the average similarity). Community groups with less than two samples (ie: Hunter Lowlands Redgum Forest, Plantation Forest) cannot be analysed in this way. Instead, the full species list from the single plot in each community is shown, in decreasing cover abundance value.

In the *Key Diagnostic Species* tables in each profile:

- **Average similarity** is the within-group similarity for all pairs of sample plots comprising the community. Higher average similarity indicates a better defined community.
- **Av.Abund** is the average cover abundance of that species within sample plots comprising the community
- **Av.Sim** is the average similarity (contribution) made by each species to the within-group similarity (the overall average similarity).
- **Sim/SD** is the ratio of average similarity to standard deviation for each species across all pairs of samples. A high ratio represents a good discriminating species. At least three samples are required for this ratio to be calculated.
- **Contrib %** is the percentage contribution of each species to the overall average similarity for the community.

Unit 1

Gully Rainforest

NSW Vegetation class (Keith 2004): **Dry Rainforests**
North East CRA **No equivalent**
LHCCREMS 3: **Hunter Valley Dry Rainforest**

General Description:

Gully Rainforest occurs only in the more rugged topography of the Stonequarry Hill section of the reserve, and is dominated by *Backhousia myrtifolia, Scolopia braunii, Melaleuca styphelioides, Syzygium australe* and *Streblus brunonianus* in the canopy, over a range of rainforest-affiliated species such as *Hibiscus heterophyllous, Dioscorea transversa, Myrsine variabilis, Podocarpus elatus, Cassine australis, Lomandra longifolia* and *Pellaea falcata*. Emergent eucalypts from the surrounding landscape are also evident, including *Corymbia maculata, Eucalyptus acmenoides, Eucalyptus canaliculata* and *Eucalyptus moluccana*.

Characteristic Features:

- narrow strips of rainforest along often rocky gully lines
- canopy dominated by *Backhousia myrtifolia* with several other rainforest tree species
- ground layer of ferns and scattered grasses

Known Floristic/ Structural Variations:

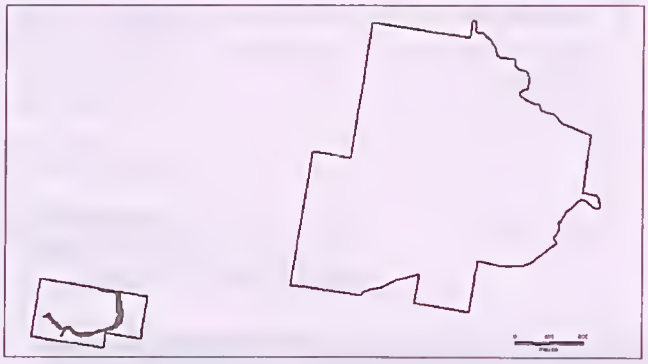
No known floristic or structural variations noted, as this community occurs only in the one drainage line within the reserve.

Relationship to Other Communities:

Gully Rainforest is most similar to Riparian Rainforest (Unit 2), but supports a higher diversity of rainforest trees and shrubs. *Backhousia myrtifolia* is clearly dominant in Gully Rainforest, but commonly occurs with other dry rainforests species such as *Scolopia braunii, Podocarpus elatus, Syzygium australe* and *Streblus brunonianus*. Gully Rainforest also occurs in rocky gullies on steeper terrain, rather than the deep alluvial sands of the Riparian Rainforest.

Community Conservation Status:

Reserve Representation –	unknown from other reserves but likely to occur on the Lower North Coast
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	not currently listed.



Distribution:

Columbey NP (main portion)	not present
Columbey NP (Stonequarry Hill)	6.75 ha
Total	6.75 ha

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *none recorded*

Species Richness:

Number of plots:	2
Total native species:	70
Mean species / plot (+/- SD):	50.5 (+/- 7.78)

Key Diagnostic Species [based on 2 plots]:

Gully Rainforest
Average similarity: 55.09

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Backhousia myrtifolia*	5.00	5.99	-	10.87
	Melaleuca styphelioides	3.00	3.59	-	6.52
	Eucalyptus acmenoides	2.00	2.40	-	4.35
	Drypetes deplanchei	1.00	1.20	-	2.17
	Elaeodendron australe var. *australe*	1.50	1.20	-	2.17
	Melicope micrococca	1.50	1.20	-	2.17
Shrub	*Hibiscus heterophyllus* subsp. *heterophyllus*	2.00	2.40	-	4.35
	Scolopia braunii	2.50	2.40	-	4.35
	Streblus brunonianus	2.50	2.40	-	4.35
	Breynia oblongifolia	1.00	1.20	-	2.17
	Clerodendrum tomentosum	1.00	1.20	-	2.17
	Glochidion ferdinandi var. *ferdinandi*	1.50	1.20	-	2.17
	Notelaea longifolia forma *longifolia*	1.50	1.20	-	2.17
Grass	*Oplismenus imbecillis*	2.50	2.40	-	4.35
Herb/ Forb	*Desmodium gunnii*	2.00	2.40	-	4.35
	Pseuderanthemum variabile	2.00	2.40	-	4.35
Fern	*Adiantum hispidulum*	1.50	1.20	-	2.17
	Pellaea falcata	1.00	1.20	-	2.17
Sedge	*Carex maculata*	2.50	2.40	-	4.35
	Gahnia melanocarpa	1.00	1.20	-	2.17
Vine	*Pandorea pandorana*	2.00	2.40	-	4.35
	Aphanopetalum resinosum	1.50	1.20	-	2.17
	Cissus antarctica	1.00	1.20	-	2.17
	Dioscorea transversa	1.50	1.20	-	2.17
	Geitonoplesium cymosum	1.50	1.20	-	2.17
	Morinda jasminoides	1.50	1.20	-	2.17
	Parsonsia straminea	1.00	1.20	-	2.17

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	24.5	21.5	27.5	22.5	3.5	2
Middle 1	9.8	6.0	13.5	77.5	3.5	2
Middle 2	-	-	-	-	-	-
Middle 3	-	-	-	-	-	-
Lowest	1.5	0.6	2.5	35.0	21.2	2

Unit 2

Riparian Rainforest

NSW Vegetation class (Keith 2004):	**Dry Rainforests**
North East CRA	**No equivalent**
LHCCREMS1:	**Coastal Wet Gully Forest (?)**

General Description:

Riparian Rainforest occurs along major creeklines such as Wallaroo Creek, on deep sandy alluvium, and is characterised by *Tristaniopsis laurina, Backhousia myrtifolia, Melicope micrococca, Acronychia wilcoxianum, Acmena smithii,* and *Cryptocarya microneura*. Emergent eucalypts (eg: *E. acmenoides, E. tereticornis*) are also present, as are the occasional *Casuarina cunninghamiana* and **Grevillea robusta*. The latter species does not naturally occur south of Coffs Harbour on the far North Coast (Harden 1991), but has naturalised probably from plantings in nearby Clarence Town.

Characteristic Features:

- narrow strips of rainforest on deep sandy soils adjacent to larger creeks
- canopy dominated by *Acmena smithii, Backhousia myrtifolia* and several other species, with *Tristaniopsis laurina* and *Ficus coronata*
- common along watercourses
- ground layer of ferns

Known Floristic/ Structural Variations:

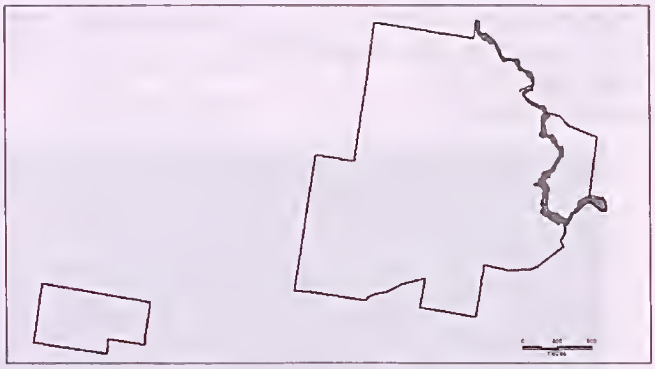
Depending on the history of flooding within creeklines supporting this vegetation type, ground layer ferns and herbs may be variable in both composition and abundance. In some areas, emergent Cabbage Gum (*Eucalyptus amplifolia*) occur with rainforest species, particularly where in close proximity to Floodplain Redgum – Box Forest.

Relationship to Other Communities:

Riparian Rainforest is most similar to Gully Rainforest (Unit 1), but supports fewer rainforest species and tends to be dominated by *Acmena smithii, Melicope micrococca, Tristaniopsis laurina* and *Backhousia myrtifolia*. Gully Rainforest also occurs in rocky gullies on steeper terrain, rather than the deep alluvial sands of the Riparian Rainforest. **Grevillea robusta* (not locally indigenous) occurs only in Riparian Rainforest, where it has attained true canopy status in some areas.

Community Conservation Status:

Reserve Representation –	unknown from other reserves but likely to occur on the Lower North Coast
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	not currently listed.



Distribution:

Columbey NP (main portion)	20.16 ha
Columbey NP (Stonequarry Hill)	not present
Total 20.16 ha	

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *none recorded*

Species Richness:

Number of plots:	3
Total native species:	55
Mean species / plot (+/- SD):	34.3 (+/- 7.37)

Key Diagnostic Species [based on 3 plots]:

Riparian Rainforest
Average similarity: 52.33

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Backhousia myrtifolia*	3.67	4.94	8.31	9.43
	Melicope micrococca	3.00	3.82	4.37	7.29
	Tristaniopsis laurina	2.67	3.79	5.69	7.24
	Acronychia wilcoxiana	2.33	2.70	1.53	5.15
	Acmena smithii	2.67	2.17	2.50	4.15
	Acacia maidenii	2.00	1.87	0.58	3.57
	Angophora floribunda	1.67	1.25	0.58	2.38
	Eucalyptus acmenoides	1.67	1.25	0.58	2.38
	Grevillea robusta *	1.67	1.05	0.58	2.01
	Cryptocarya microneura	1.67	1.00	0.58	1.90
Shrub	*Breynia oblongifolia*	1.00	1.65	8.31	3.14
	Ficus coronata	1.00	1.65	8.31	3.14
	Notelaea longifolia forma *longifolia*	1.00	1.65	8.31	3.14
	Pittosporum multiflorum	1.33	1.05	0.58	2.01
	Maytenus silvestris	0.67	0.62	0.58	1.19
Grass	*Oplismenus imbecillis*	2.67	3.29	8.31	6.29
Herb/ Forb	*Pseuderanthemum variabile*	1.33	1.00	0.58	1.90
Fern	*Adiantum aethiopicum*	2.00	3.29	8.31	6.29
	Doodia aspera	2.00	1.57	0.58	3.01
Sedge	*Gymnostachys anceps*	0.67	0.62	0.58	1.19
Vine	*Morinda jasminoides*	2.00	2.14	2.88	4.09
	Geitonoplesium cymosum	1.33	1.65	8.31	3.14
	Pandorea pandorana	1.33	1.65	8.31	3.14
	Parsonsia straminea	1.33	1.65	8.31	3.14

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	21.0	18.7	23.3	26.7	5.8	3
Middle 1	10.5	6.0	15.0	78.3	7.6	3
Middle 2	-	-	-	-	-	-
Middle 3	-	-	-	-	-	-
Lowest	0.2	0.1	0.4	11.7	11.6	3

Unit 3

Paperbark Soak Forest

NSW Vegetation class (Keith 2004): Coastal Floodplain Wetlands
North East CRA: No equivalent
LHCCREMS 42: Riparian Melaleuca Swamp Woodland (?)

General Description:

Paperbark Soak Forest occurs sporadically along shallow drainage lines and is dominated by *Melaleuca linariifolia*, occasionally with *Melaleuca styphelioides*, over a dense ground layer of *Carex longebrachiata*, *Carex appressa* and other sedge species. Emergent eucalypts (*Eucalyptus tereticornis*, *E. amplifolia* subsp. *amplifolia*, *E. siderophloia*) are also present in many locations. Many small examples of this community occur within the Floodplain Redgum-Box Forest, to which they are strongly linked.

Characteristic Features:

- Low, dense canopy dominated by *Melaleuca linariifolia* and *Melaleuca styphelioides*
- standing pools of water, billabongs etc often present
- ground layer of *Carex longebrachiata, Carex appressa* and other sedges, grasses and herbs

Known Floristic/ Structural Variations:

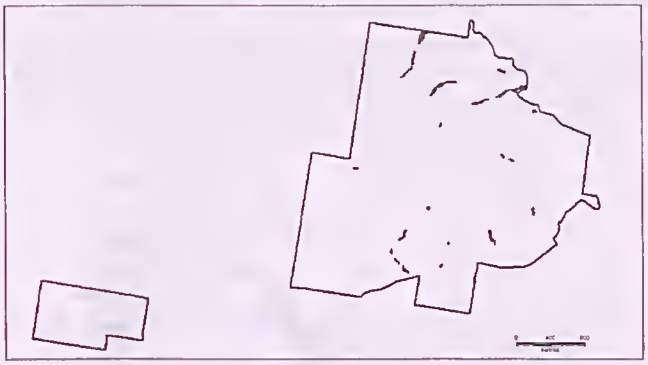
No known floristic or structural variations noted.

Relationship to Other Communities:

Paperbark Soak Forest is floristically and structurally distinct from all other defined communities in the reserve. The low, dense canopy of *Melaleuca linariifolia*, ground layer of sedges and grasses, and presence of standing water in billabongs are not replicated elsewhere. Small stands of *Melaleuca* may occur within the Floodplain Redgum – Box Forest (Unit 4), but these tend to highly localised.

Community Conservation Status:

Reserve Representation – known Werakata NP (DECC 2008)
EPBC Act (1999) Status – not currently listed.
TSC Act (1995) Status – not currently listed.



Distribution:

Columbey NP (main portion)	4.87 ha
Columbey NP (Stonequarry Hill)	not present
Total	4.87 ha

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *none recorded*

Species Richness:

Number of plots: 4
Total native species: 69
Mean species / plot (+/- SD): 35.5 (+/- 1.92)

Key Diagnostic Species [based on 4 plots]:

Paperbark Soak Forest
Average similarity: 58.77

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Melaleuca linariifolia*	5.50	8.20	18.35	13.95
Shrub	*Acacia irrorata* subsp. *irrorata*	1.50	1.86	2.81	3.16
	Leucopogon juniperinus	1.00	1.59	23.09	2.71
	Notelaea longifolia forma *longifolia*	1.00	1.59	23.09	2.71
	Leptospermum polygalifolium subsp. *cismontanum*	1.25	1.03	0.83	1.75
	Callistemon linearis	0.75	0.77	0.91	1.32
Grass	*Oplismenus imbecillis*	3.00	3.95	5.16	6.73
	Microlaena stipoides var. *stipoides*	2.00	3.18	23.09	5.41
	Entolasia marginata	1.50	1.85	2.99	3.14
	Imperata cylindrica var. *major*	1.75	1.61	0.91	2.73
Graminoid	*Dianella caerulea* var. *assera*	1.00	1.59	23.09	2.71
Herb/ Forb	*Dichondra repens*	2.00	3.18	23.09	5.41
	Hydrocotyle laxiflora	2.00	3.18	23.09	5.41
	Pratia purpurascens	2.00	3.18	23.09	5.41
	Centella asiatica	1.50	1.61	0.91	2.73
	Oxalis perennans	1.00	0.82	0.91	1.40
	Hydrocotyle peduncularis	1.00	0.80	0.91	1.37
	Polymeria calycina	1.00	0.78	0.91	1.33
	Veronica plebeia	1.00	0.78	0.91	1.33
Sedge	*Carex longebrachiata*	5.25	7.95	23.09	13.53
Vine	*Parsonsia straminea*	1.50	1.87	2.51	3.19
	Glycine clandestina	1.25	1.59	23.09	2.71

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	16.6	15.3	18.0	28.8	41.1	4
Middle 1	6.1	4.8	7.5	57.5	35.7	4
Middle 2	-	-	-	-	-	-
Middle 3	-	-	-	-	-	-
Lowest	0.4	0.1	0.7	91.3	2.5	4

Unit 4

Floodplain Redgum – Box Forest

NSW Vegetation class (Keith 2004):	**Coastal Floodplain Wetlands**
North East CRA E54:	**Grey Box – Redgum- Grey Ironbark (?)**
LHCCREMS	**No equivalent**

General Description:

Floodplain Redgum – Box Forest is restricted to major creeklines and their associated flood-outs. It can be dominated by any of *Eucalyptus amplifolia* subsp *amplifolia*, *Eucalyptus siderophloia*, *Eucalyptus tereticornis* or *Eucalyptus moluccana*. Examples dominated by each are present within the reserve, which are readily recognised in the field. *Angophora floribunda* also occurs as a canopy dominant in limited areas. Some locations have been previously cleared and now support regrowth vegetation, while others appear not to have been overly disturbed. This community equates to the River-Flat Eucalypt Forest on Coastal Floodplains EEC (NSW Scientific Committee 2005a).

Characteristic Features:

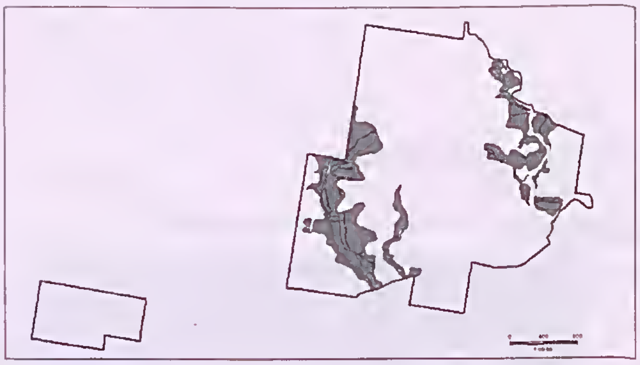
- canopy dominated by any of *Eucalyptus amplifolia* subsp *amplifolia*, *Eucalyptus moluccana*, *Angophora floribunda* or *Eucalyptus siderophloia*
- ground layer dominated by grasses and herbs
- occurs on low-lying flats adjacent to major drainage lines, commonly regrowth following past grazing activities

Known Floristic/ Structural Variations:

Five main variants have been noted in the field for this community, all characterised by different canopy dominants. Any of Cabbage Gum (*Eucalyptus amplifolia* subsp. *amplifolia*), Grey Box (*Eucalyptus moluccana*), Rough-barked Apple (*Angophora floribunda*), Forest Redgum (*Eucalyptus tereticornis*), or Northern Grey Ironbark (*Eucalyptus siderophloia*) can dominate an area, however targeted sampling and analysis could not sufficiently differentiate between them. Areas where *Eucalyptus tereticornis* is characteristic are invariably along creeks and are heavily invaded by **Lantana camara*, making sampling difficult. It is likely that analysis incorporating data from further afield (outside of Columbey NP) would justify elevating these variants to community status.

Relationship to Other Communities:

The often mono-specific stands of *Eucalyptus amplifolia*, *Eucalyptus moluccana*, *Angophora floribunda* or *Eucalyptus siderophloia* characterise this community, and cannot be confused with any other vegetation type. They also occur in low lying terrain in close proximity to drainage lines. Stands of *Eucalyptus siderophloia* may be confused with Plantation Forest (Unit 12), but canopy species in that community are planted in rows and should be easily distinguished.



Distribution:

Columbey NP (main portion)	124.4 ha
Columbey NP (Stonequarry Hill)	not present
Total	124.4 ha

Community Conservation Status:

Reserve Representation –	known Werakata NP (DECC 2008)
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	forms a component of *River flat Eucalypt Forest on Coastal Floodplains* EEC.

Significant Species:

Undescribed species – *none recorded*

Threatened (EPBC Act) – *none recorded*

Threatened (TSC Act) – *none recorded*

Rare (ROTAP) – *none recorded*

Species Richness:

Number of plots:	8
Total native species:	137
Mean species / plot (+/- SD):	51.1 (+/- 6.20)

Key Diagnostic Species [based on 8 plots]:

Floodplain Redgum – Box Forest
Average similarity: 48.96

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Eucalyptus moluccana*	2.38	1.38	0.72	2.83
	Eucalyptus amplifolia subsp. *amplifolia*	1.50	0.49	0.34	1.01
	Eucalyptus siderophloia	1.00	0.24	0.34	0.49
Shrub	*Leucopogon juniperinus*	1.50	1.33	3.21	2.71
	Acacia irrorata subsp. *irrorata*	1.88	0.99	0.78	2.02
	Bursaria spinosa	1.25	0.84	1.56	1.71
	Breynia oblongifolia	0.88	0.57	1.05	1.16
	Maytenus silvestris	0.63	0.40	0.73	0.83
	Notelaea longifolia forma *longifolia*	0.75	0.39	0.73	0.79
Grass	*Microlaena stipoides* var. *stipoides*	3.63	3.56	5.97	7.26
	Aristida vagans	2.38	1.83	1.59	3.73
	Cymbopogon refractus	2.38	1.83	1.59	3.73
	Panicum simile	1.50	1.18	1.05	2.41
	Echinopogon caespitosus var. *caespitosus*	1.38	0.94	0.97	1.92
	Paspalidium distans	1.63	0.89	0.72	1.82
	Eragrostis brownii	1.38	0.75	0.73	1.53
	Entolasia marginata	1.13	0.71	0.97	1.44
	Oplismenus imbecillis	1.25	0.65	0.68	1.34
	Themeda australis	1.25	0.38	0.46	0.78
	Echinopogon ovatus	1.00	0.34	0.48	0.70
	Eragrostis leptostachya	0.88	0.25	0.34	0.52
Graminoid	*Dianella revoluta* var. *revoluta*	1.38	1.21	3.90	2.48
	Dianella caerulea var. *assera*	1.25	1.14	5.70	2.33
	Lomandra confertifolia subsp. *pallida*	1.25	0.77	0.73	1.57
	Lomandra multiflora subsp. *multiflora*	0.88	0.41	0.69	0.85
Herb / Forb	*Dichondra repens*	2.25	2.24	10.04	4.58
	Brunoniella australis	1.88	1.93	3.75	3.95
	Vernonia cinerea var. *cinerea*	1.75	1.70	2.92	3.47
	Pratia purpurascens	1.75	1.65	1.69	3.37
	Plantago debilis	1.50	1.20	1.05	2.46
	Oxalis perennans	1.50	1.15	1.05	2.35
	Lagenophora stipitata	1.50	1.13	1.05	2.30
	Centella asiatica	1.13	0.64	0.68	1.30
	Euchiton involucratus	1.00	0.50	0.67	1.03
	Hydrocotyle laxiflora	1.00	0.49	0.51	1.00
Fern	*Cheilanthes sieberi* subsp. *sieberi*	1.75	1.60	1.70	3.27
Sedge	*Gahnia aspera*	2.13	1.98	3.45	4.04
	Fimbristylis dichotoma	1.63	1.42	1.50	2.90
	Carex longebrachiata	1.50	0.80	0.72	1.63
Vine	*Glycine tabacina*	1.88	1.94	3.68	3.96
	Glycine clandestina	0.75	0.29	0.48	0.59

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	19.1	17.3	21.0	32.5	7.1	8
Middle 1	8.4	5.4	11.3	19.4	7.3	8
Middle 2	2.3	1.3	3.3	37.9	38.1	8
Middle 3	-	-	-	-	-	-
Lowest	0.4	0.1	0.7	87.5	8.2	6

Unit 5

Seaham Mahogany Forest
NSW Vegetation class (Keith 2004): **North Coast Wet Sclerophyll Forests**
North East CRA E89: **Moist Foothills Spotted Gum (?)**
LHCCREMS 12: **Hunter Valley Moist Forest (?)**

General Description:

Seaham Mahogany Forest is dominated by *Eucalyptus acmenoides, Eucalyptus siderophloia, Eucalyptus placita* and *Allocasuarina torulosa*, and occurs on well sheltered slopes such as the southern side of Tower Hill in the main portion of the reserve. The understorey is dominated by *Notelaea longifolia* forma *longifolia* and includes a high diversity of grasses and herbs such as *Microlaena stipoides* var. *stipoides, Oplismenus imbecillus, Desmodium gunnii, Pratia purpurascens, Veronica plebeia* and *Scutellaria humilis*.

Characteristic Features:

- canopy dominated by *Eucalyptus acmenoides, Allocasuarina torulosa* and *Eucalyptus siderophloia*
- occurs on sheltered slopes of higher relief areas
- herbs and grasses dominate the ground layer

Known Floristic/ Structural Variations:

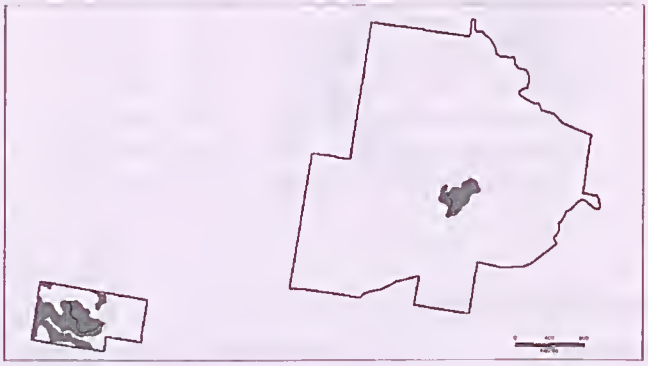
No known floristic or structural variations noted.

Relationship to Other Communities:

The dominance of *Eucalyptus acmenoides* and *Allocasuarina torulosa* in the canopy of this community distinguish it from all others in the reserve. This community also only occurs on sheltered slopes of the higher relief areas, and supports a rich ground layer of herbs and grasses. Some areas may be difficult to distinguish between this community and the adjacent Seaham Spotted Gum – Ironbark Forest (Unit 7), but the co-dominance of Spotted Gum in the latter can be used as a rule of thumb in this case.

Community Conservation Status:

Reserve Representation –	unknown from other reserves but likely to occur on the Lower North Coast
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	not currently listed.



Distribution:

Columbey NP (main portion)	10.37 ha
Columbey NP (Stonequarry Hill)	28.86 ha
Total	39.23 ha

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	20.9	18.5	23.3	41.3	6.3	4
Middle 1	6.3	4.7	7.9	11.3	2.5	4
Middle 2	-	-	-	-	-	-
Middle 3	-	-	-	-	-	-
Lowest	0.4	0.1	0.7	38.8	22.1	4

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *Macrozamia flexuosa*

Species Richness:

Number of plots:	4
Total native species:	125
Mean species / plot (+/- SD):	59.3(+/- 4.86)

Key Diagnostic Species [based on 4 plots]:

Seaham Mahogany Forest
Average similarity: 46.28

Habit	**Species**	**Av. Abund**	**Av. Sim**	**Sim/ SD**	**Contrib%**
Tree	*Eucalyptus acmenoides*	3.50	3.18	8.06	6.88
	Allocasuarina torulosa	2.50	2.18	5.12	4.71
	Corymbia maculata	2.50	2.02	1.80	4.36
	Eucalyptus siderophloia	2.25	1.17	0.88	2.52
Shrub	*Acacia implexa*	1.50	1.17	2.92	2.53
	Leucopogon juniperinus	1.75	1.17	3.01	2.53
	Notelaea longifolia forma *longifolia*	1.75	1.17	3.01	2.53
	Breynia oblongifolia	1.25	1.01	54.75	2.17
	Clerodendrum tomentosum	0.75	0.50	0.91	1.08
	Maytenus silvestris	0.75	0.50	0.91	1.07
	Myrsine variabilis	1.00	0.50	0.91	1.07
Subshrub	*Hibbertia diffusa*	1.00	0.50	0.91	1.08
	Pomax umbellata	1.00	0.50	0.91	1.08
Grass	*Panicum simile*	2.25	2.01	54.75	4.34
	Imperata cylindrica var. *major*	2.50	1.68	2.04	3.63
	Oplismenus imbecillis	1.75	0.99	0.91	2.14
	Poa labillardierei var. *labillardierei*	1.75	0.99	0.91	2.14
	Microlaena stipoides var. *stipoides*	1.50	0.49	0.41	1.06
	Entolasia stricta	1.00	0.34	0.41	0.73
Graminoid	*Lomandra multiflora* subsp. *multiflora*	1.25	0.67	0.81	1.45
	Dianella caerulea var. *assera*	1.25	0.66	0.82	1.42
	Lomandra longifolia	1.00	0.50	0.91	1.07
Herb/ Forb	*Desmodium gunnii*	2.00	2.01	54.75	4.34
	Dichondra repens	2.00	2.01	54.75	4.34
	Pratia purpurascens	2.00	2.01	54.75	4.34
	Pseuderanthemum variabile	1.75	1.51	2.68	3.27
	Brunoniella australis	1.50	0.99	0.91	2.14
	Oxalis perennans	1.25	0.66	0.81	1.43
	Plectranthus parviflorus	1.00	0.51	0.91	1.10
	Vernonia cinerea var. *cinerea*	1.00	0.51	0.91	1.10
Vine	*Glycine clandestina*	2.00	2.01	54.75	4.34
	Pandorea pandorana	2.00	2.01	54.75	4.34
	Desmodium rhytidophyllum	1.25	1.01	54.75	2.17
	Eustrephus latifolius	1.25	1.01	54.75	2.17
	Desmodium brachypodum	1.25	0.68	0.82	1.46
	Hardenbergia violacea	1.00	0.50	0.91	1.08
	Cissus opaca	0.75	0.50	0.91	1.07

Unit 6

Seaham Ironbark Forest

NSW Vegetation class (Keith 2004): **Coastal Valley Grassy Woodlands**
North East CRA E33: **Dry Foothills Spotted Gum (?)**
LHCCREMS 16: **Seaham Spotted Gum-Ironbark Forest**

General Description:

Seaham Ironbark Forest occurs in two areas of the reserve, both of which have been disturbed by previous clearing and grazing, and both are dominated by even-aged stands of *Eucalyptus crebra* and/ or *Eucalyptus siderophloia*. Shrubs are generally sparse or absent, but a diverse ground layer of grasses and herbs is present. It is probable that this community is an artefact of past clearing, and has been recolonised by nearby standing remnant trees, particularly *Eucalyptus crebra*.

Characteristic Features:

- canopy dominated by *Eucalyptus crebra* and, in some places, *Eucalyptus siderophloia*
- even-aged stands of eucalypts following previous clearing and grazing
- ground layer of numerous grasses and herbs

Known Floristic/ Structural Variations:

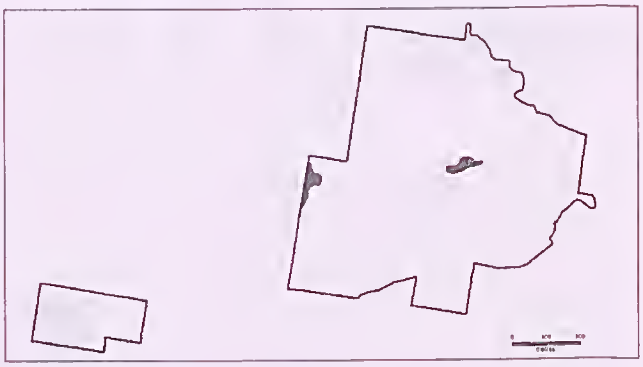
Northern Grey Ironbark (*Eucalyptus siderophloia*) may co-occur with the more characteristic Narrow-leaved Ironbark (*Eucalyptus crebra*) in some areas.

Relationship to Other Communities:

Almost mono-specific stands of *Eucalyptus crebra* (+/- *E. siderophloia*) over a grassy understorey distinguish this community from all others. There may be some confusion with Seaham Spotted Gum – Ironbark Forest (Unit 7) due to the presence of *Eucalyptus crebra* also in that community, however the co-dominance of *Corymbia maculata* in the latter can be used to split the two.

Community Conservation Status:

Reserve Representation –	unknown from other reserves but likely to occur on the Lower North Coast
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	not currently listed.



Distribution:

Columbey NP (main portion)	8.19 ha
Columbey NP (Stonequarry Hill)	not present
Total	8.19 ha

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	15.8	13.5	18.0	35.0	0.0	2
Middle 1	1.9	1.3	2.5	16.5	19.1	2
Middle 2	-	-	-	-	-	-
Middle 3	-	-	-	-	-	-
Lowest	0.4	0.1	0.7	87.5	10.6	2

Significant Species:

Undescribed species – *none recorded*

Threatened (EPBC Act) – *none recorded*

Threatened (TSC Act) – *none recorded*

Rare (ROTAP) – *none recorded*

Species Richness:

Number of plots: 2

Total native species: 68

Mean species / plot (+/- SD): 49.5 (+/- 3.54)

Key Diagnostic Species [based on 2 plots]:

Seaham Ironbark Forest
Average similarity: 56.67

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Eucalyptus crebra*	3.50	3.33	-	5.88
Shrub	*Acacia implexa*	1.50	1.11	-	1.96
	Acacia irrorata subsp. *irrorata*	1.50	1.11	-	1.96
	Breynia oblongifolia	1.50	1.11	-	1.96
Grass	*Cymbopogon refractus*	2.50	2.22	-	3.92
	Echinopogon ovatus	2.00	2.22	-	3.92
	Microlaena stipoides var. *stipoides*	3.00	2.22	-	3.92
	Panicum effusum	2.50	2.22	-	3.92
	Paspalidium distans	2.50	2.22	-	3.92
	Themeda australis	3.50	2.22	-	3.92
	Echinopogon caespitosus var. *caespitosus*	1.50	1.11	-	1.96
Graminoid	*Dianella caerulea* var. *assera*	1.00	1.11	-	1.96
Herb/ Forb	*Brunoniella australis*	2.00	2.22	-	3.92
	Dichondra repens	2.00	2.22	-	3.92
	Hypericum gramineum	2.00	2.22	-	3.92
	Hypoxis hygrometrica var. *villosisepala*	2.00	2.22	-	3.92
	Lagenophora stipitata	2.00	2.22	-	3.92
	Oxalis perennans	2.00	2.22	-	3.92
	Pratia purpurascens	2.00	2.22	-	3.92
	Vernonia cinerea var. *cinerea*	2.00	2.22	-	3.92
	Centella asiatica	1.50	1.11	-	1.96
Fern	*Cheilanthes sieberi* subsp. *sieberi*	2.00	2.22	-	3.92
Sedge	*Fimbristylis dichotoma*	2.00	2.22	-	3.92
	Carex longebrachiata	1.50	1.11	-	1.96
Vine	*Glycine clandestina*	2.00	2.22	-	3.92
	Glycine tabacina	2.00	2.22	-	3.92

Unit 7

Seaham Spotted Gum – Ironbark Forest

NSW Vegetation class (Keith 2004): **Hunter-Macleay Dry Sclerophyll Forests**

North East CRA E33: **Dry Foothills Spotted Gum (?)**

LHCCREMS 16: **Seaham Spotted Gum-Ironbark Forest**

General Description:

Seaham Spotted Gum – Ironbark Forest is dominated by *Eucalyptus siderophloia, Eucalyptus crebra, Corymbia maculata* and *Eucalyptus moluccana*, often with *Eucalyptus tereticornis*. It occurs on the higher ridges and hills, such as Tower Hill, and understorey species include *Bursaria spinosa, Acacia falcata, Lissanthe strigosa, Jacksonia scoparia, Cymbopogon refractus, Themeda australis, Aristida vagans*, and a high diversity of herbs.

Characteristic Features:

- canopy dominated by *Eucalyptus siderophloia, Eucalyptus crebra, Eucalyptus tereticornis, Eucalyptus moluccana* and *Corymbia maculata*
- occurs on the higher elevation areas, on ridgetops and at exposed aspects
- shrubs such as *Jacksonia scoparia* and *Bursaia spinosa* characteristic

Known Floristic/ Structural Variations:

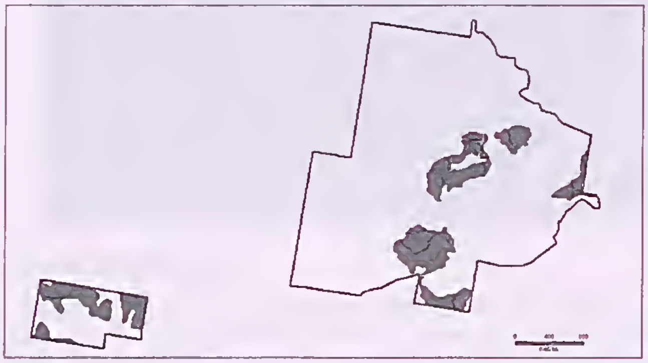
No known floristic or structural variations noted.

Relationship to Other Communities:

The presence of *Eucalyptus siderophloia*, *Eucalyptus crebra*, *Eucalyptus tereticornis* and *Eucalyptus moluccana*, with *Corymbia maculata* distinguish this community from all others. Lower Hunter Spotted Gum – Ironbark Forest (Unit 8) is superficially similar, but in that community the dominant ironbark species is *Eucalyptus fibrosa* and it occurs at lower elevations on the more gentle slopes and ridges.

Community Conservation Status:

Reserve Representation –	known from Wallaroo and Karuah NRs
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	not currently listed.



Distribution:

Columbey NP (main portion)	74.7 ha
Columbey NP (Stonequarry Hill)	32.0 ha
Total	106.7 ha

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *Macrozamia flexuosa*

Species Richness:

Number of plots:	4
Total native species:	109
Mean species / plot (+/- SD):	57.2 (+/- 8.10)

Key Diagnostic Species [based on 4 plots]:

Seaham Spotted Gum – Ironbark Forest
Average similarity: 51.15

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Corymbia maculata*	2.75	2.51	4.43	4.90
	Eucalyptus umbra	2.00	1.32	1.81	2.57
	Eucalyptus tereticornis	1.25	0.50	0.91	0.97
	Eucalyptus crebra	1.75	0.44	0.41	0.86
Shrub	*Bursaria spinosa*	2.75	2.17	5.19	4.25
	Acacia falcata	2.00	1.50	2.74	2.94
	Acacia implexa	1.75	1.47	3.42	2.87
	Pultenaea villosa	1.50	1.20	2.18	2.34
	Acacia ulicifolia	1.50	1.16	3.27	2.27
	Leucopogon juniperinus	1.50	1.16	3.27	2.27
	Breynia oblongifolia	1.00	1.01	9.98	1.97
	Persoonia linearis	0.75	0.46	0.91	0.91
Subshrub	*Pomax umbellata*	1.00	0.46	0.91	0.91
Grass	*Aristida vagans*	2.50	2.19	4.05	4.28
	Cymbopogon refractus	2.75	2.16	7.70	4.22
	Microlaena stipoides var. *stipoides*	2.25	2.01	9.98	3.93
	Dichelachne micrantha	1.75	1.47	3.42	2.87
	Entolasia stricta	2.00	1.47	3.42	2.87
	Panicum simile	1.50	0.93	0.91	1.81
Graminoid	*Lomandra multiflora* subsp. *multiflora*	1.75	1.54	2.31	3.01
	Lomandra confertifolia subsp. *pallida*	1.75	1.20	2.18	2.34
	Lomandra longifolia	1.25	1.01	9.98	1.97
	Dianella caerulea var. *assera*	1.50	0.93	0.91	1.81
	Dianella revoluta var. *revoluta*	0.75	0.50	0.91	0.97
Herb/ Forb	*Pratia purpurascens*	2.00	2.01	9.98	3.93
	Brunoniella australis	1.75	1.50	2.74	2.94
	Lagenophora stipitata	1.50	1.04	0.91	2.02
	Phyllanthus hirtellus	1.50	1.04	0.91	2.02
	Dichondra repens	1.50	0.93	0.91	1.81
	Desmodium gunnii	1.25	0.70	0.85	1.36
	Vernonia cinerea var. *cinerea*	1.25	0.62	0.81	1.21
Fern	*Cheilanthes sieberi* subsp. *sieberi*	2.00	2.01	9.98	3.93
Sedge	*Lepidosperma laterale*	2.00	1.52	2.46	2.98
	Gahnia aspera	1.00	0.46	0.91	0.91
Vine	*Glycine clandestina*	1.75	1.47	3.42	2.87
	Glycine tabacina	1.50	1.17	2.95	2.28
	Desmodium rhytidophyllum	1.25	0.62	0.81	1.21
	Eustrephus latifolius	1.00	0.53	0.91	1.05

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	18.5	17.0	20.0	33.8	2.5	4
Middle 1	3.5	2.2	4.8	26.3	27.2	4
Middle 2	-	-	-	-	-	-
Middle 3	-	-	-	-	-	-
Lowest	0.4	0.1	0.7	75.0	19.2	4

Unit 8

Lower Hunter Spotted Gum – Ironbark Forest

NSW Vegetation class (Keith 2004): **Hunter-Macleay Dry Sclerophyll Forests**
North East CRA E75: **Lowlands Spotted Gum-Box (?)**
LHCCREMS 17: **Lower Hunter Spotted Gum-Ironbark Forest**

General Description:

Lower Hunter Spotted Gum – Ironbark Forest is dominated by *Eucalyptus fibrosa, Corymbia maculata* and *Eucalyptus umbra*. In places, *Eucalyptus moluccana* can also be present. This community occupies the lower undulating slopes at low elevation, with typical understorey species including *Daviesia ulicifolia* subsp. *ulicifolia, Bursaria spinosa, Pultenaea villosa, Entolasia stricta, Aristida vagans, Macrozamia flexuosa*, and *Lomandra confertifolia* subsp. *pallida*. This community is consistent with the Final Determination for the EEC of the same name (NSW Scientific Committee 2005b).

Characteristic Features:

- canopy dominated by *Eucalyptus fibrosa* and *Corymbia maculata*, with *Eucalyptus umbra* also present in some areas
- shrub layer of *Daviesia ulicifolia* subsp. *ulicifolia, Bursaria spinosa* and *Pultenaea villosa*
- ground layer dominated by grasses such as *Entolasia stricta, Aristida vagans* and *Microlaena stipoides* var. *stipoides*

Known Floristic/ Structural Variations:

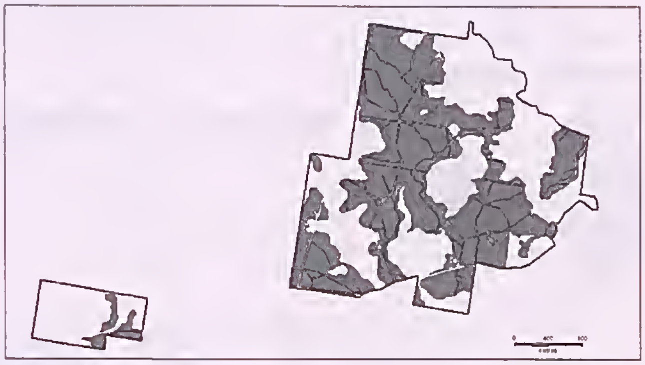
In some locations, small stands of *Melaleuca nodosa* may occasionally occur, which superficially resemble the Red Ironbark – Paperbark Scrub-Forest. However, these stands are always highly localised.

Relationship to Other Communities:

The co-dominance of *Corymbia maculata* and *Eucalyptus fibrosa*, often with *Eucalyptus umbra*, distinguish this community from all others. The closely related Red Ironbark Scrub-Forest (Unit 9) can be confused with this community, but *Corymbia maculata* is very sparse or absent in that community, and *Melaleuca nodosa* forms characteristic dense stands in the mid-storey.

Community Conservation Status:

Reserve Representation –	known from Werakata NP & SCA (DECC 2008) and Sugarloaf SCA (Bell & Driscoll 2009)
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	consistent with *Lower Hunter Spotted Gum – Ironbark Forest* EEC



Distribution:

Columbey NP (main portion)	407.09 ha
Columbey NP (Stonequarry Hill)	12.11 ha
Total	419.2 ha

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *Macrozamia flexuosa*

Species Richness:

Number of plots:	8
Total native species:	109
Mean species / plot (+/- SD):	48.6 (+/- 3.50)

Key Diagnostic Species [based on 8 plots]:

Lower Hunter Spotted Gum Ironbark Forest
Average similarity: 61.69

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Eucalyptus fibrosa*	3.50	3.85	7.17	6.24
	Corymbia maculata	3.25	3.63	15.31	5.89
	Eucalyptus umbra	1.75	1.17	0.93	1.89
Shrub	*Bursaria spinosa*	2.50	2.65	5.03	4.30
	Pultenaea villosa	2.13	1.51	1.18	2.45
	Leucopogon juniperinus	1.38	1.33	3.46	2.15
	Acacia falcata	1.25	1.24	4.70	2.02
	Persoonia linearis	1.38	1.14	1.41	1.86
	Acacia ulicifolia	2.00	1.14	0.75	1.85
	Daviesia ulicifolia subsp. *ulicifolia*	1.50	1.04	0.98	1.69
	Lissanthe strigosa subsp. *subulata*	1.00	0.66	1.01	1.07
Subshrub	*Pomax umbellata*	1.63	1.55	1.47	2.51
	Brachyscome multifida var. *multifida*	1.50	1.30	1.40	2.11
	Hibbertia diffusa	0.88	0.64	1.05	1.03
Grass	*Entolasia stricta*	3.50	3.52	4.70	5.71
	Aristida vagans	2.75	2.69	4.29	4.36
	Microlaena stipoides var. *stipoides*	2.00	2.40	17.07	3.88
	Panicum simile	1.88	2.10	3.76	3.41
	Paspalidium distans	1.50	1.26	1.05	2.05
	Themeda australis	1.38	1.12	1.41	1.82
	Cymbopogon refractus	1.25	1.01	1.48	1.64
	Eragrostis brownii	1.13	0.77	0.95	1.25
Graminoid	*Lomandra multiflora* subsp. *multiflora*	1.63	1.61	2.91	2.62
	Lomandra filiformis subsp. *coriacea*	1.63	1.52	1.50	2.47
	Dianella revoluta var. *revoluta*	1.50	1.47	2.63	2.38
	Dianella caerulea var. *assera*	1.25	1.02	1.45	1.65
	Lomandra longifolia	1.25	0.78	0.96	1.26
Herb/Forb	*Pratia purpurascens*	2.00	2.40	17.07	3.88
	Phyllanthus hirtellus	1.88	2.09	4.03	3.38
	Goodenia heterophylla subsp. *heterophylla*	1.25	0.81	0.73	1.32
	Brunoniella australis	1.13	0.80	0.94	1.29
Fern	*Cheilanthes sieberi* subsp. *sieberi*	2.00	2.40	17.07	3.88
Sedge	*Lepidosperma laterale*	1.38	1.07	0.96	1.73
Vine	*Glycine clandestina*	1.50	1.31	1.40	2.13
	Hardenbergia violacea	0.88	0.90	1.69	1.47

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	17.3	15.8	18.8	32.5	3.8	8
Middle 1	5.2	3.0	7.5	30.6	29.6	8
Middle 2	1.4	0.7	2.1	42.1	26.1	8
Middle 3	-	-	-	-	-	-
Lowest	0.4	0.1	0.7	60.0	25.5	5

Unit 9

Red Ironbark Scrub-Forest

NSW Vegetation class (Keith 2004):	**Hunter-Macleay Dry Sclerophyll Forests**
North East CRA	**No equivalent**
LHCCREMS	**17: Lower Hunter Spotted Gum-Ironbark Forest**

General Description:

Red Ironbark Scrub-Forest is dominated by *Eucalyptus fibrosa* over a dense understorey of *Melaleuca nodosa*. *Corymbia maculata* may also be present but in low abundance. This community occurs toward the north of the reserve, and supports a number of more typically sandstone-based species such as *Phyllota phylicoides*, *Lomandra glauca*, *Gompholobium pinnatum*, *Patersonia sericea*, *Dillwynia retorta*, *Xanthorrhoea latifolia* subsp. *latifolia* and *Banksia spinulosa* var. *collina*. It is similar to vegetation in the Cessnock LGA which forms a component of the Lower Hunter Spotted Gum – Ironbark Forest EEC (DECC 2008).

Characteristic Features:

- canopy dominated by *Eucalyptus fibrosa* and (very occasionally) *Corymbia maculata*
- mid layer of dense stands of *Melaleuca nodosa*, *Hakea sericea* and *Callistemon linearis*
- occurs on erodible clay soils

Known Floristic/ Structural Variations:

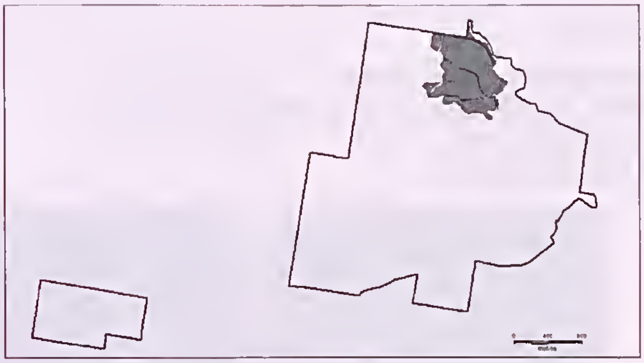
No known floristic or structural variations noted.

Relationship to Other Communities:

Dense stands of *Melaleuca nodosa* under a canopy of mostly *Eucalyptus fibrosa* distinguish this community from the closely related Lower Hunter Spotted Gum – Ironbark Forest (Unit 8). No other community within the reserve is characterised by *Melaleuca nodosa* in the understorey.

Community Conservation Status:

Reserve Representation –	known from Werakata NP & SCA (DECC 2008)
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	forms a component of *Lower Hunter Spotted Gum – Ironbark Forest* EEC



Distribution:

Columbey NP (main portion)	56.21 ha
Columbey NP (Stonequarry Hill)	not present
Total	56.21 ha

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	15.3	12.7	18.0	20.0	0.0	3
Middle 1	5.6	3.8	7.3	61.7	40.4	3
Middle 2	-	1.5	4.0	85.0	-	1
Middle 3	-	-	-	-	-	-
Lowest	0.4	0.1	0.7	46.7	34.0	3

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *Macrozamia flexuosa*

Species Richness:

Number of plots:	3
Total native species:	70
Mean species / plot (+/- SD):	47.7 (+/- 6.11)

Key Diagnostic Species [based on 3 plots]:

Red Ironbark Scrub–Forest
Average similarity: 68.96

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Eucalyptus fibrosa*	3.67	3.98	11.00	5.77
	Corymbia maculata	2.00	1.62	2.15	2.35
Shrub	*Melaleuca nodosa*	6.00	7.23	12.92	10.48
	Lissanthe strigosa subsp. *subulata*	2.00	2.41	12.92	3.49
	Pultenaea myrtoides	2.00	2.41	12.92	3.49
	Phyllota phylicoides	1.67	1.57	2.89	2.28
	Dendrophthoe vitellina	1.00	1.21	12.92	1.75
	Pultenaea villosa	1.00	1.21	12.92	1.75
	Callistemon rigidus	1.33	0.83	0.58	1.20
	Callistemon linearis	1.33	0.73	0.58	1.06
	Hakea sericea	1.67	0.73	0.58	1.06
Subshrub	*Gonocarpus tetragynus*	2.00	2.41	12.92	3.49
Grass	*Entolasia stricta*	2.67	2.83	3.27	4.11
	Aristida vagans	2.00	2.41	12.92	3.49
	Microlaena stipoides var. *stipoides*	2.00	2.41	12.92	3.49
	Joycea pallida	1.67	1.57	2.89	2.28
	Aristida warburgii	1.33	0.73	0.58	1.06
Graminoid	*Dianella revoluta* var. *revoluta*	2.00	2.41	12.92	3.49
	Lomandra filiformis subsp. *filiformis*	2.33	2.41	12.92	3.49
	Lomandra glauca	2.00	2.41	12.92	3.49
Herb/Forb	*Goodenia bellidifolia* subsp. *bellidifolia*	2.00	2.41	12.92	3.49
	Phyllanthus hirtellus	2.00	2.41	12.92	3.49
	Pratia purpurascens	1.67	1.57	2.89	2.28
	Lagenophora stipitata	1.00	1.21	12.92	1.75
	Thysanotus tuberosus subsp. *tuberosus*	1.00	1.21	12.92	1.75
	Drosera auriculata	1.33	0.73	0.58	1.06
	Goodenia heterophylla subsp. *heterophylla*	1.33	0.73	0.58	1.06
Fern	*Cheilanthes sieberi* subsp. *sieberi*	2.00	2.41	12.92	3.49
Sedge	*Philothrix deusta*	2.33	2.41	12.92	3.49
Vine	*Cassytha glabella* forma *glabella*	2.00	2.41	12.92	3.49
	Hardenbergia violacea	1.00	1.21	12.92	1.75

Unit 10

Stringybark - Apple Forest
NSW Vegetation class (Keith 2004): **Hunter-Macleay Dry Sclerophyll Forests**
North East CRA **No equivalent**
LHCCREMS 30: **Coastal Plains Smooth-barked Apple Woodland (?)**

General Description:

Stringybark – Apple Forest occurs in two locations within the wider Lower Hunter Spotted Gum – Ironbark Forest landscape. It is dominated by *Eucalyptus globoidea*, but with *Angophora costata* or *Eucalyptus fibrosa* present in one area. This community is typified by the presence of more typical sandstone species, such as *Banksia spinulosa* var. *collina*, *Xanthorrhoea latifolia*, *Podolobium scandens*, *Laxmannia gracilis*, *Gompholobium pinnatum* and *Aristida warburgii*. Given the small size of both locations present, it is not surprising that their floristic composition is heavily influenced by the surrounding Lower Hunter Spotted Gum – Ironbark Forest.

Characteristic Features:

- canopy dominated by *Eucalyptus globoidea*, and in some areas *Angophora costata*
- *Xanthorrhoea latifolia* often present, together with *Banksia spinulosa* var. *collina*
- ground layer of grasses and sandstone-based subshrubs such as *Gompholobium pinnatum*

Known Floristic/ Structural Variations:

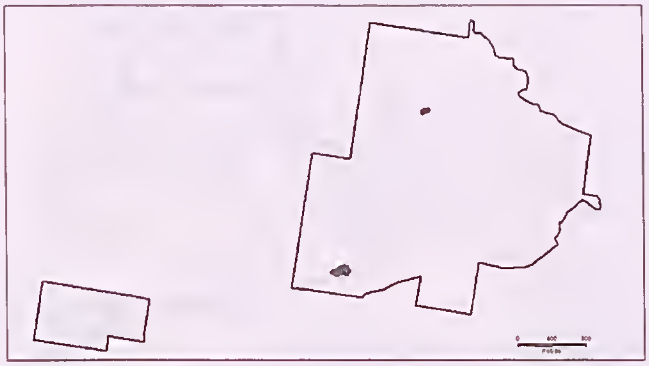
Smooth-barked Apple (*Angophora costata*) is prominent in one location, however White Stringybark (*Eucalyptus globoidea*) clearly characterises this community.

Relationship to Other Communities:

The dominance of *Eucalyptus globoidea* in the canopy distinguish this community from all others. *Angophora costata* may also be present in some areas, and neither species occurs to any great extent in other communities. The presence of ground layer species such as *Banksia spinulosa* var. *collina*, *Xanthorrhoea latifolia*, *Podolobium scandens*, *Laxmannia gracilis*, *Gompholobium pinnatum* and *Aristida warburgii* may also aid identification, but these species are present in some other communities, particularly Red Ironbark Scrub-Forest (Unit 9).

Community Conservation Status:

Reserve Representation –	unknown from other reserves but likely to occur on the Lower North Coast
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	not currently listed.



Distribution:

Columbey NP (main portion)	2.67 ha
Columbey NP (Stonequarry Hill)	not present
Total	2.67 ha

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *none recorded*

Species Richness:

Number of plots:	2
Total native species:	78
Mean species / plot (+/- SD):	53.5 (+/- 9.19)

Key Diagnostic Species [based on 2 plots]:

Stringybark – Apple Forest
Average similarity: 51.06

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Eucalyptus globoidea*	4.00	4.26	-	8.33
Shrub	*Lissanthe strigosa* subsp. *subulata*	2.00	2.13	-	4.17
	Acacia ulicifolia	2.00	1.06	-	2.08
	Callistemon linearis	1.00	1.06	-	2.08
	Persoonia linearis	1.50	1.06	-	2.08
Grass	*Entolasia stricta*	3.00	3.19	-	6.25
	Aristida vagans	2.50	2.13	-	4.17
	Microlaena stipoides var. *stipoides*	2.00	2.13	-	4.17
	Panicum simile	2.00	2.13	-	4.17
	Paspalidium distans	2.00	2.13	-	4.17
	Themeda australis	3.00	2.13	-	4.17
Gram-inoid	*Lomandra filiformis* subsp. *coriacea*	2.00	2.13	-	4.17
	Lomandra multiflora subsp. *multiflora*	2.00	2.13	-	4.17
	Lomandra longifolia	1.50	1.06	-	2.08
Herb/ Forb	*Brunoniella australis*	2.00	2.13	-	4.17
	Phyllanthus hirtellus	2.00	2.13	-	4.17
	Pratia purpurascens	2.00	2.13	-	4.17
	Drosera auriculata	1.00	1.06	-	2.08
	Microtis unifolia	1.00	1.06	-	2.08
Fern	*Cheilanthes sieberi* subsp. *sieberi*	2.00	2.13	-	4.17
Sedge	*Philothrix deusta*	2.50	2.13	-	4.17
	Lepidosperma laterale	1.50	1.06	-	2.08
Vine	*Glycine clandestina*	2.00	2.13	-	4.17
	Billardiera scandens	1.50	1.06	-	2.08
	Cassytha glabella forma *glabella*	1.50	1.06	-	2.08

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	19.8	18.0	21.5	32.5	3.5	2
Middle 1	7.5	5.0	10.0	5.0	0.0	2
Middle 2	1.3	0.8	1.8	19.0	22.6	2
Middle 3	-	-	-	-	-	-
Lowest	0.4	0.1	0.8	82.5	3.5	2

Hunter Lowlands Redgum Forest

Unit 11

NSW Vegetation class (Keith 2004): Coastal Valley Grassy Woodlands
North East CRA: No equivalent
LHCCREMS 19: Hunter Lowlands Redgum Forest

General Description:

Hunter Lowlands Redgum Forest occurs at a single location in a previously cleared and grazed landscape, where it is dominated by *Eucalyptus tereticornis* over a grassy ground layer of *Themeda australis, Aristida warburgii, Aristida vagans* and *Ptilothrix deusta*. Shrubs such as *Acacia falcata, Acacia irrorata* subsp. *irrorata, Pultenaea villosa* and *Bursaria spinosa* are also present. The floristic composition present at this site is consistent with the Final Determination for the EEC of the same name (NSW Scientific Committee 2003).

Characteristic Features:

- canopy dominated almost exclusively by *Eucalyptus tereticornis*
- occurs on low relief slopes near creeklines
- ground layer of grasses such as *Themeda australis, Aristida warburgii* and *Eragrostis brownii*

Known Floristic/ Structural Variations:

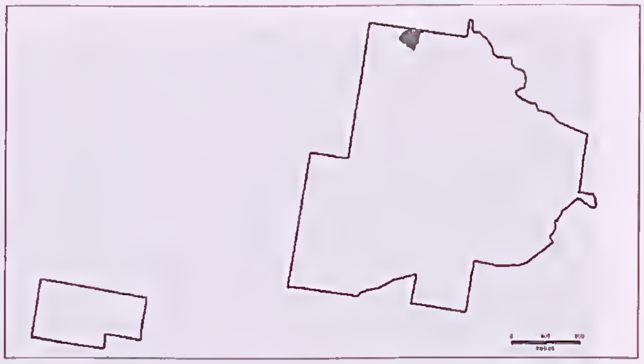
No known floristic or structural variations noted.

Relationship to Other Communities:

Dominant stands of *Eucalyptus tereticornis* characterise this community, which is not repeated elsewhere in the reserve. This species is occasionally present in the Floodplain Redgum – Box Forest (Unit 4), but that community is dominated by *Eucalyptus amplifolia, Eucalyptus moluccana* or *Eucalyptus siderophloia*.

Community Conservation Status:

Reserve Representation –	known from Werakata NP (DECC 2008)
EPBC Act (1999) Status –	not currently listed.
TSC Act (1995) Status –	forms a component of *Hunter Lowlands Redgum Forest* EEC.



Distribution:

Columbey NP (main portion)	3.68 ha
Columbey NP (Stonequarry Hill)	not present
Total	3.68 ha

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *none recorded*

Species Richness:

Number of plots:	1
Total native species:	49
Mean species / plot (+/- SD):	49 (+/- n/a)

Key Diagnostic Species [based on 1 plot]:

Hunter Lowlands Redgum Forest
Less than 2 samples in group

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Eucalyptus tereticornis*	-	-	-	-
Shrub	*Acacia falcata*	-	-	-	-
	Acacia irrorata subsp. *irrorata*	-	-	-	-
	Breynia oblongifolia	-	-	-	-
	Bursaria spinosa	-	-	-	-
	Daviesia ulicifolia subsp. *ulicifolia*	-	-	-	-
	Hibbertia aspera subsp. *aspera*	-	-	-	-
	Leptospermum polygalifolium subsp. *cismontanum*	-	-	-	-
	Leucopogon juniperinus	-	-	-	-
	Lissanthe strigosa subsp. *subulata*	-	-	-	-
	Logania albiflora	-	-	-	-
	Persoonia linearis	-	-	-	-
	Pultenaea villosa	-	-	-	-
Grass	*Aristida vagans*	-	-	-	-
	Aristida warburgii	-	-	-	-
	Austrodanthonia setacea	-	-	-	-
	Cymbopogon refractus	-	-	-	-
	Echinopogon ovatus	-	-	-	-
	Entolasia stricta	-	-	-	-
	Eragrostis brownii	-	-	-	-
	Imperata cylindrica var. *major*	-	-	-	-
	Microlaena stipoides var. *stipoides*	-	-	-	-
	Oplismenus imbecillis	-	-	-	-
	Panicum simile	-	-	-	-
	Paspalidium distans	-	-	-	-
	Themeda australis	-	-	-	-
Graminoid	*Dianella revoluta* var. *revoluta*	-	-	-	-
	Lomandra filiformis subsp. *coriacea*	-	-	-	-
	Lomandra longifolia	-	-	-	-
	Lomandra multiflora subsp. *multiflora*	-	-	-	-
Herb/ Forb	*Chrysocephalum apiculatum*	-	-	-	-
	Dichondra repens	-	-	-	-
	Eriochilus cucullatus	-	-	-	-
	Goodenia bellidifolia subsp. *bellidifolia*	-	-	-	-
	Hypoxis hygrometrica var. *villosisepala*	-	-	-	-
	Lagenophora stipitata	-	-	-	-
	Opercularia diphylla	-	-	-	-
	Oxalis perennans	-	-	-	-
	Phyllanthus hirtellus	-	-	-	-
	Pomax umbellata	-	-	-	-
	Pratia purpurascens	-	-	-	-
Sedge	*Gahnia aspera*	-	-	-	-
	Lepidosperma laterale	-	-	-	-
	Ptilothrix deusta	-	-	-	-
Fern	*Cheilanthes sieberi* subsp. *sieberi*	-	-	-	-
Vine	*Billardiera scandens*	-	-	-	-
	Glycine clandestina	-	-	-	-
	Glycine tabacina	-	-	-	-
	Parsonsia straminea	-	-	-	-

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	-	18.0	20.0	25.0	-	1
Middle 1	-	6.0	15.0	10.0	-	1
Middle 2	-	1.5	4.0	20.0	-	1
Middle 3	-	-	-	-	-	-
Lowest	-	0.1	0.7	85.0	-	1

Unit 12

Plantation Forest	
NSW Vegetation class (Keith 2004):	**No equivalent**
North East CRA	**No equivalent**
LHCCREMS	**No equivalent**

General Description:

Between Plantation Road and Clarencetown Road, areas of plantation eucalypt forest occur, in mostly well-defined rows. For all intents and purposes these areas possess a native understorey of species typical of elsewhere in the reserve. Planted eucalypts noted include all locally occurring species, such as *Eucalyptus siderophloia* (dominant), *Eucalyptus fibrosa*, *Eucalyptus tereticornis*, *Eucalyptus moluccana* and *Corymbia maculata*. An area of *Callitris endlicheri* (not locally indigenous) is also present adjacent to Clarencetown Road. Other areas of plantation include *Eucalyptus resinifera*, particularly towards the middle of the reserve adjacent to Wallaroo Ck.

Characteristic Features:

- canopy dominated by any of *Eucalyptus siderophloia*, *Eucalyptus fibrosa*, *Eucalyptus tereticornis*, *Eucalyptus moluccana*, *Corymbia maculata*, *Eucalyptus resinifera*, or *Callitris endlicheri*, all planted in rows
- shrub layer poorly developed or absent
- ground layer of grasses and herbs

Known Floristic/ Structural Variations:

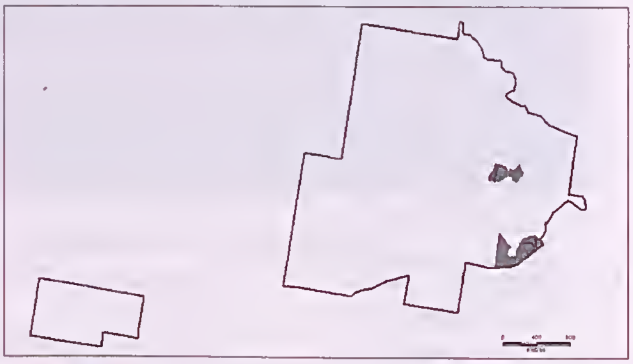
Planted canopy species varies throughout the mapped areas of this community. Northern Grey Ironbark (*Eucalyptus siderophloia*) tends to dominate most areas, and Red Mahogany (*Eucalyptus resinifera*) is most common in the more northern plantation area.

Relationship to Other Communities:

Although the majority of species present within this community are represented elsewhere in the reserve in several other communities, the linear rows of canopy species clearly separates this community from all others. In addition, Black Cypress Pine is not present in any other community, either within the reserve or locally elsewhere.

Community Conservation Status:

Reserve Representation –	not applicable
EPBC Act (1999) Status –	not applicable
TSC Act (1995) Status –	not applicable



Distribution:

Columbey NP (main portion)	16.65 ha
Columbey NP (Stonequarry Hill)	not present
Total	16.65 ha

Significant Species:

Undescribed species – *none recorded*
Threatened (EPBC Act) – *none recorded*
Threatened (TSC Act) – *none recorded*
Rare (ROTAP) – *none recorded*

Species Richness:

Number of plots:	1
Total native species:	45
Mean species / plot (+/- SD):	45 (+/- n/a)

Key Diagnostic Species [based on 1 plot]:

Plantation Forest
Less than 2 samples in group

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Tree	*Eucalyptus siderophloia*	-	-	-	-
	Eucalyptus tereticornis	-	-	-	-
Shrub	*Acacia ulicifolia*	-	-	-	-
	Acrotriche divaricata	-	-	-	-
	Breynia oblongifolia	-	-	-	-
	Bursaria spinosa	-	-	-	-
	Cassinia uncata	-	-	-	-
	Leptospermum polygalifolium subsp. *polygalifolium*	-	-	-	-
	Lissanthe strigosa subsp. *subulata*	-	-	-	-
	Notelaea longifolia f. longifolia	-	-	-	-
	Persoonia linearis	-	-	-	-
	Pultenaea villosa	-	-	-	-
Subshrub	*Chrysocephalum apiculatum*	-	-	-	-
Grass	*Aristida vagans*	-	-	-	-
	Cymbopogon refractus	-	-	-	-
	Dichelachne micrantha	-	-	-	-
	Echinopogon ovatus	-	-	-	-
	Entolasia stricta	-	-	-	-
	Microlaena stipoides var. *stipoides*	-	-	-	-
	Notodanthonia longifolia	-	-	-	-
	Panicum simile	-	-	-	-
	Poa labillardierei var. *labillardierei*	-	-	-	-
	Themeda australis	-	-	-	-

Plantation Forest
Less than 2 samples in group

Habit	Species	Av. Abund	Av. Sim	Sim/ SD	Contrib%
Graminoid	*Dianella caerulea* var. *assera*	-	-	-	-
	Dianella revoluta var. *revoluta*	-	-	-	-
	Lomandra multiflora subsp. *multiflora*	-	-	-	-
Herb/Forb	*Brunoniella australis*	-	-	-	-
	Dichondra repens	-	-	-	-
	Euchiton sphaericus	-	-	-	-
	Goodenia bellidifolia subsp. *bellidifolia*	-	-	-	-
	Hibbertia diffusa	-	-	-	-
	Hydrocotyle laxiflora	-	-	-	-
	Microtis unifolia	-	-	-	-
	Opercularia diphylla	-	-	-	-
	Phyllanthus hirtellus	-	-	-	-
	Poranthera microphylla	-	-	-	-
	Pratia purpurascens	-	-	-	-
Sedge	*Lepidosperma laterale*	-	-	-	-
	Ptilothrix deusta	-	-	-	-
	Schoenus apogon	-	-	-	-
Fern	*Cheilanthes sieberi* subsp. *sieberi*	-	-	-	-
Vine	*Eustrephus latifolius*	-	-	-	-
	Glycine clandestina	-	-	-	-
	Parsonsia straminea	-	-	-	-
	Polymeria calycina	-	-	-	-

Vegetation Structure:

Stratum	Mean height (m)	Min height (m)	Max height (m)	Mean cover (%)	Sdev	n
Emergent	-	-	-	-	-	-
Tallest	-	18.0	22.0	35.0	-	1
Middle 1	-	1.0	2.5	50.0	-	1
Middle 2	-	-	-	-	-	-
Middle 3	-	-	-	-	-	-
Lowest	-	0.1	0.7	75.0	-	1

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